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PRELIMINARY STUDIES ON THE BIOGEOCHEMISTRY OF IRON AND MANGANESE.

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ABSTRACT.

Naturally a prospector prefers to find an outcrop of ore rather than discover an area which merely offers encouragement for further investigations. However as outcrops of ore become harder and harder to find and as the search for new mines intensifies, the discovery even of an area which justifies further detailed study becomes increasingly important.

Just as mineralogists and geologists have turned to indirect methods, such as pathfinder minerals and ore halos, for help in their search for ore, so the biogeochemist may well turn to a study of elements, which although they may not be those that are being sought, may, by their presence in abnormal amounts, suggest anomalous conditions which in turn may justify a detailed search for ore in a particular area.

This introductory paper describes our preliminary investigations into the practicability of using iron and manganese as biogeochemical pathfinders. These investigations are not an attempt to solve the complex problem of the iron and manganese distribution in trees; the aim is merely to show how iron and manganese vary not only in different organs but also in the same organs of trees if the trees have grown under different conditions. Naturally we have been particularly interested in the biogeochemistry of areas where there are known to be unusually high or low amounts of iron or manganese in the subsoil. Brief mention will be made of possible correlations between our work and some current hypotheses concerned with the relationships which may exist between the iron and manganese contents of plants.

HISTORY AND BACKGROUND.

At present this investigation may best be considered an appendage to our previous studies dealing with the biogeochemistry of copper and zinc (7).[1] The majority of the samples considered in this paper were not collected for the specific purpose of this study. In the course of analytical operations it was impossible to overlook the very high iron and manganese contents of some copper or zinc rich samples. Eventually it became established practice to determine iron and manganese in an aliquot of the solution from which the copper had already been extracted with dithizone. Lately much research has been

[1] Numbers in parentheses refer to Bibliography at end of paper.

undertaken with the specific problem of iron and manganese in mind but this paper has been completed in part with the aid of data which we had collected while doing other work during the past five years.

It is important to note that although much is known about the iron and manganese contents of plants, a great deal of the data have been obtained for the needs of agriculture, and that comparatively, little is known about the iron and manganese contents of plants growing naturally. A naturalist can hardly consider as normal the overfed varieties of trees and lesser plants which hoard unusual amounts of the products of metabolism and which are unable to subsist in some areas without the assistance of man. It is dangerous to generalize, but it must be kept in mind that agricultural chemists have been chiefly concerned with these species which were having difficulties in adapting themselves to places where they had been artificially established. Under such conditions wild species are usually absent.

When investigating relationships between the copper and zinc contents of trees and the nature or mineralization of the subsoil, we established that great variations of these elements might occur between different organs of the same plant. Young twigs, one or two seasons old, seemed the best type of sample to analyze, because they showed the greatest regularity of composition relative to any particular type of subsoil. For this reason much of the data in this paper concerns such twigs and this fact should not be taken to mean that they are the best specimens for iron and manganese investigations.

Furthermore we have assembled absolutely different data from those obtained in the Province of Quebec by Gamelin (4) for conifers and Delorme (2) for deciduous trees. These men determined the iron and manganese contents of different organs of a small number of trees for each species, each species growing as far as possible in pure stands. Our investigations, although they have extended over a great variety of geological formations, various climates, and have included sufficient numbers in some areas to permit the preparation of frequency diagrams or "histograms," have been limited to a relatively few organs.

SOME WORKING HYPOTHESES.

Since M. O. Johnson (5) published his results numerous investigations have shown that iron and manganese are interrelated in plant physiology. For example, an excess of manganese, or the soil conditions that lead to it, is held to be responsible for iron deficiency which leads to chlorosis. Gamelin (4) noticed that the iron and manganese contents of wild trees tended to vary inversely with one another. In the majority of cases our results agree with Gamelin's observations but they do not implement them completely. As will be seen from our results, plants from hot dry areas tend to be rich in iron and poor in manganese whereas plants rich in manganese came mostly from swampy places or areas of heavy rainfall. However, these features although general were by no means invariable. Neither have we satisfied ourselves that it is safe to assume that where both metals are high the one which might have been expected to be low is high because of abnormally high contents of that element in the subsoil.

Amounts of iron and manganese in a given organ of a given species appear to vary much more widely than do the corresponding amounts of zinc and copper. Nevertheless for a limited area the frequency diagrams for iron and manganese are just as distinctive as those for copper and zinc and therefore the distribution of iron and manganese may be expected to obey rules although the rules are not yet fully understood and certainly are not simple. However there is little likelihood of finding amounts of iron and manganese that may be termed normal and that will vary little between any group of plants found associated in their natural surroundings. Some species, such as Silver Birch—*Betula papyrifera* and Black Spruce—*Picea mariana*—may be considered as manganese-rich but under special conditions they may be iron-rich as well; we have found this to be the case with Western Hemlock—*Tsuga heterophylla*.

It is well to know that the bulk of the metal content of trees and lesser plants is present in some precipitated inactive form and that the greater amount of metal present in ash is an excretion of the cells and can therefore, in some cases, accumulate without any objectionable effect, provided that the intake is slow enough.

In spite of our having made several hundred analyses of iron and manganese it seems that our data are inadequate for us to be able to formulate definite rules as to the amount of iron and manganese that may be considered normal under various circumstances. It seems clear that isolated analyses should be replaced by frequency diagrams, and this, of course, means determinations by the thousands instead of by the hundreds which were necessary in the simpler case of copper and zinc.

Nevertheless it is already possible under the conditions prevailing on vast areas of the northern hemisphere to interpret the data obtained on the iron and manganese contents of some organs of some of the more common genera of trees and lesser plants. Our ultimate goal is to use the biogeochemistry of iron and manganese in prospecting, and for determining the nature of different rocks under drift. We have still a long way to go but we now have enough evidence to believe that this goal may be reached before many years are ended.

ANALYTICAL METHODS.

Manganese.

The formaldoxime reagent of Bach (1) proved to be more sensitive and more reliable for small amounts than the classical permanganic acid colorimetric methods.

Reagents Used.—(a) Formaldoxime Solution. Add three grams of trioxymethylene, or the equivalent amount of formaldehyde solution, to seven grams of hydroxylamine hydrochloride. Then with water make up to 15 ml and boil until perfectly clear (after Denigès, 1932). This reagent is very stable and can be kept for months. (b) Sodium Hydroxide. Use 10 *N* solution in water.

Procedure.—To 5 to 10 ml of nearly neutral solution containing from 5 to 50 γ ($1\ \gamma = 1.10^{-6}$ gram or one millionth gram), add one drop of form-

aldoxime and 3 drops of caustic sodium hydroxide. More alkali should be added if the solution has been buffered heavily. Amounts of metal hydroxides in plant ash are not *normally* large enough to interfere, otherwise their precipitation must somehow be prevented. Color appears immediately but is mixed with the color of other metal complexes, especially iron. Leave the test tube for two minutes in a boiling water bath and all colors will be destroyed, except those of manganese and cobalt. As the color caused by the latter is much less intense and the amounts involved are extremely small, the interference from cobalt is negligible. In practice, the only appreciable disturbance could be caused by ferric iron, in amounts above 50 γ per ml—that is in amounts which are quite rarely met with in samples taken from a wet climate. However, in amounts above 50 γ per ml ferric iron may destroy the manganese complex during the water bath treatment, and this may cause unduly low results. The use of hydroxylamine or hydrazine salts to prevent this destruction of the manganese complex is not always satisfactory and best results can be obtained by adding sodium acetate, after the 3 drops of caustic sodium hydroxide are introduced, and precipitating iron near the boiling point and then pipetting from the clear upper part of the solution for manganese colorimetry. Then match the colors with a series of standards of similar content. Results agree well with those obtained by the better known persulphate method. Standards must be made every day, but they keep better than permanganic standards.

Iron.

In the presence of dipyridyl and in a solution of low acidity, trivalent iron is reduced quantitatively by hydroxylamine and gives a red-colored complex. The formation of this complex removes the ferrous ions and ensures thoroughness of the reaction. The ferric salts that precipitate on diluting the acid solution of plant ash are usually present in a very dispersed state and the reaction is complete in a few hours, at the most.

Reagents Used.—(a) Dipyridyl solution. Dissolve 1 gram of dipyridyl in a few ml of 0.2 *N* hydrochloric acid and make up to one litre. (b) Hydroxylamine hydrochloride. 20 grams per litre. (c) Hydrochloric acid. 3 *N*. (d) Acetate buffer. Take 250 grams of hydrated sodium acetate and 11 ml of glacial acetic acid and make up to 1 litre.

Procedure.—To a neutral or slightly acid solution containing 5 to 70 γ of iron in a few ml add a few drops of 3 *N* hydrochloric acid, 1 ml of hydroxylamine, 1 ml of dipyridyl, mix and add buffer until a red color develops and then a small excess. Let stand at least half an hour. The color must not change on adding a little buffer; if it does add some more. When the color is stable on adding buffer adjust to 10 ml and compare with standard solutions. Eye matching with standards of similar contents gives results comparable with those given by the thiocyanate method. The dipyridyl color is more sensitive, and much more stable. Standards can be safely kept for weeks and even longer.

The amounts of metals that might cause interference are quite small in plant ash.

SOME FACTORS AFFECTING THE BIOGEOCHEMISTRY OF IRON AND MANGANESE.

The Selectivity of Different Species of Trees.

Early in our investigations we found that different species growing on the same soil would contain, both relatively and absolutely, different amounts of iron and manganese. Analyses of several hundred suites of samples and statistical studies of a few species have served to demonstrate that the variations are consistent and that various species of trees have varying affinities for iron and manganese.

The following table serves to illustrate the varying affinity of a few species of trees for iron and manganese. All these samples were collected during the summer of 1949 in the Tweedsmuir Park area of British Columbia. Tips of evergreens and young stems of deciduous species have been used throughout.

In each suite every effort was made to collect all the samples from as similar an environment as was practical; in many instances it was possible to collect suites with the roots of several species actually intermingling.

The results in all the tables that follow are expressed in ppm (parts per million) of dry plant material. In many instances calculations have been simplified and results are expressed to the nearest 5 or 10 as the case may be.

From a study of Table 1 it is possible to state that under comparable conditions hemlock (*Tsuga heterophylla*) will contain most manganese and cottonwood (*Populus trichocarpa*) the least: other species will carry intermediate amounts. Similarly, under like conditions alder (*Alnus sitchensis*) may be expected to have an iron content nearly twice that of its associates.

The Age and Specific Organ Selected.

Investigations of Gamelin (4) and Delorme (2) have shown that the iron and manganese contents of different organs of the same tree can vary considerably. In our earlier investigations these variations had little significance for us because it was our custom to mill into a coarse powder the whole of a bough of the tree which was to be tested. However, demands for speed and efficiency in fieldwork dictated a decrease in the weight of sample from one hundred grams to one gram. Boughs were abandoned for leaves or twigs, and eventually twigs alone. At this stage we found that various organs contained varying amounts of iron and manganese. This was of vital importance. Furthermore, the mineral content of an organ varied with its age and each element had to be investigated separately. In most coniferous species the needles fall easily on drying and consequently the needles used in the following table are mixed, usually, however, being one or two years old.

It will be seen from the following table that the iron and manganese variations are far greater than those of copper and zinc (6, 7).

All the samples from which analyses of Table 2 were taken came from an area ranging in elevation from four to five thousand feet and having a rainfall, including snowfall, of from sixty to eighty inches. The samples were collected in spring after most of the snow had melted.

We could present much more data of a similar character. However,

TABLE 1.

VARIATIONS IN THE IRON AND MANGANESE CONTENT OF DIFFERENT SPECIES GROWING IN CLOSE ASSOCIATION.

Suite No.	Alpine Fir *Abies lasiocarpa*			Western Hemlock *Tsuga heterophylla*			White Spruce *Picea Glauca*			Lodgepole Pine *Pinus contorta*			Black Cottonwood *Populus trichocarpa*			Green Alder *Alnus sinuata*		
	Fe	Mn	Fe:Mn	Fe	Mn	Fe:Mn	Fe	Mn	Fe:Mn	Fe	Mn	Fe:Mn	Fe	Mn	Fe:Mn	Fe	Mn	Fe:Mn
26.49	20	175	.15				20	250	.08	25	300	.08	15	20	.75	45	65	.69
27.49	15	160	.09				10	60	.17	15	250	.06	25	30	.83	25	75	.30
29.49	15	150	.10				15	125	.11	10	175	.06	25	5	5.00	35	150	.23
31.49	25	80	.31				15	60	.25	25	250	.10	20	15	1.33	35	50	.70
33.49	15	150	.10							20	80	.25	20	10	2.00	40	40	1.00
35.49	15	200	.07	10	375	.03	15	150	.10	30	150	.20	25	30	.83			
36.49	15	100	.15				10	125	.08	15	225	.07	15	10	1.50	40	60	.67
40.49	20	250	.08				15	100	.14	25	300	.08	30	20	1.50	50	50	1.00
41.49	20	250	.08							15	150	.10				40	60	.67
45.49	20	625	.03	20	750	.03							30	100	.30	45	100	.45
46.49	35	140	.21	20	500	.04	10	90	.11							35	130	.27
49.49	20	450	.04	70	300	.23							25	20	1.25	40	125	.32
52.49	20	560	.03	20	435	.05				20	125	.16				30	125	.24
53.49	15	250	.06							25	125	.20	15	10	1.50	30	110	.27
60.49	15	350	.04				15	350	.04	15	150	.10				45	80	.56
78.49	15	150	.10	25	650	.04										20	110	.18
87.49	25	125	.20										20	20	1.00	45	80	.56
96.49	20	200	.10							20	310	.06	15	25	.60	45	150	.30
Total	345	4,365		165	3,000		125	1,310		260	2,590		280	315		645	1,560	
Average	20	240	.08	25	500	.05	15	150	.10	20	200	.10	20	25	.80	40	90	.45

TABLE 2.

VARIATIONS IN THE IRON AND MANGANESE CONTENT OF DIFFERENT AND VARIOUSLY AGED ORGANS OF THE SAME TREE.

		Sample No. 1			Sample No. 2			Sample No. 3			Sample No. 4			Sample No. 5		
A. Tsuga heterophylla (Western Hemlock)																
One year old stem	Fe	210			120			85			140			70		
	Mn		270			400			700			450			800	
	Ash %			2.25			2.9			2.3			2.8			1.8
Two year old stem	Fe	160			160			120			220			140		
	Mn		160			440			900			330			570	
	Ash %			2.05			2.7			3.0			2.4			1.7
Tips	Fe	30			40			10			25			30		
	Mn		500			560			1,000			630			1,000	
	Ash %			3.4			3.4			3.6			4.0			3.1
Mixed leaves (Needles)	Fe	30			40			40			60			35		
	Mn		2,500			1,500			1,700			800			1,250	
	Ash %			3.63			3.5			2.75			2.75			2.25
B. Thuja plicata (Western Red Cedar)																
One year old stem	Fe	70			40			40			40			40		
	Mn		120			20			30			30			40	
	Ash %			4.0			3.6			3.5			3.3			3.7
Tips	Fe	50			50			25			35			70		
	Mn		400			70			110			80			225	
	Ash %			4.5			3.4			3.75			2.9			4.05
C. Picea Engelmanni (Engelmann Spruce)																
One year old stem	Fe	200			220			120			140			120		
	Mn		70			50			600			120			120	
	Ash %			2.4			2.6			2.0			2.5			3.2
Tips	Fe	80			60			40			150			20		
	Mn		100			70			280			150			100	
	Ash %			7.0			4.6			4.2			4.8			5.0
Mixed leaves (Needles)	Fe	35			5			25			35			20		
	Mn		125			120			2,000			350			270	
	Ash %			3.6			2.6			3.25			2.85			3.0

	Stems				Leaves
	New	1 year	2 years	3 years	
D. Betula fontinalis (Western Red Birch)					
Fe	60	40	30	20	125
Mn	50	75	15	10	125
Ash %	8.6	2.1	1.7	1.8	7.15
E. Acer glabrum (Torr) (Mountain Maple)					
Fe	20	10	10	10	100
Mn	30	40	25	25	55
Ash%	10.6	2.85	2.4	1.9	8.85
F. Alnus sinuata (Green Alder)					
Fe	1,000	385	160	—	350
Mn	100	75	50	—	75
Ash %	7.35	3.8	2.65	—	6.8

Table 2 will emphasize the points which we wish to make at the present time, namely: (a) In any attempt to ascertain the influence of outside factors on the iron and manganese contents of vegetation it is essential to select samples within narrowly defined limits. (b) Before "normal" iron and manganese can be established for any organ of any species it will be necessary to carry out many statistical studies and make many more analyses than we have so far been able to do.

We ourselves favor the use of stems of one full season's growth for further studies. Although, as may well be seen from the above tables, these stems may not carry as high values in iron or manganese as tips or leaves, their contents appear to vary less erratically. Also, these stems of one full season's growth are easier to collect, especially in the earlier part of the growing season, easier to package, less liable to salting, and simpler to ash.

The reasons for all these variations will doubtless become more apparent when more is known about the exact localization and function of these elements in plant tissue and the chemical type of combination they assume. Probably, like calcium in many animals, only a fraction of the contents is actively engaged in vital processes.

The Climate of the Area.

Relatively few plants are common to both dry and humid regions. Nevertheless the following table does suffice to show that climate must be remembered in any biogeochemical survey of a new area. In detailed investigations climate may not be an important variable because it is liable to be similar over the area which is being studied. However, in exploration work climate is a factor that must be taken into account, particularly in mountainous country. Furthermore climate alone may vitiate attempts to compare biogeochemical data obtained from distant places.

The following samples were taken from three different areas of British Columbia. These areas had rainfalls of less than 15", less than 25", and less than 45", respectively.

The vegetation was growing on a relatively thin soil layer overlying various rocks. Unfortunately, at the time these samples were being collected the significance of the effect of climate on mineral content was not appreciated. However, although the comparisons are somewhat spoilt because different types of rock are involved, it is believed that the validity of the table is such that it may be said correctly to illustrate our main point, namely that other things being equal, dry conditions tend to raise the iron contents of plants whereas wet conditions tend to raise their manganese contents.

In Table 3, year old twigs have been analyzed.

In considering Table 3 the specificity of the species must be remembered. In collecting suites from a relatively humid area on Vancouver Island—30 inches to 40 inches a year—an average of eight samples of *Thuja plicata* (Western Red Cedar) ran 120 ppm of iron.

Nevertheless determinations on a series of suites from the desert of Arizona and from wet areas elsewhere all tend to confirm the evidence of the above

TABLE 3.

VARIATIONS CAUSED BY CLIMATIC DIFFERENCES IN THE IRON AND MANGANESE CONTENT OF TREES AND LESSER PLANTS.

Species		<15"				<25"					<45"			
		Suite No.												
		3	4	5	6	7	9	10	11	12	29	31	32	35
Pseudotsuga taxifolia (Douglas Fir)	Fe		280	180	240	90	40	40	130	75	15			
	Mn		40	100	40	100	170	260	110	190	280			
Pinus ponderosa (Yellow Pine)	Fe	180	450	190	150	60	20		20	30				
	Mn	60	60	40	50	30	110		40	70				
Pinus contorta (Lodgepole Pine)	Fe							60			30	20	20	25
	Mn							100			90	80	90	120
Picea Engelmanni (Engelmann Spruce)	Fe										15	15		25
	Mn										130	75		120
Juniperus (sp.) (Juniper)	Fe						120	35		35		20		20
	Mn						40	150		140		175		500
Populus tremuloides (Aspen or Poplar)	Fe									40	15		20	
	Mn									30	25		60	
Artemisia tredentata (Sage Brush)	Fe	280	650	150	400									
	Mn	70	70	20	40									

table which suggests that, other things being equal, the drier the climate the higher will be the iron content of a plant relative to manganese.

Underlying Geological Formations.

Previous investigations (8) have shown that, other factors being constant, the nature of the underlying rock exerts a marked influence on the vegetation growing above. In order to eliminate as many outside factors as possible two suites of plants were collected, from an area near Hope, B. C., where except for the fact that one suite was growing above a typical granodiorite and the other above a reddish iron-rich conglomerate, all conditions were comparable. Only six hundred yards separated the sites of the two suites and consequently rainfall, humidity, elevation, and drainage, may be assumed to be similar.

T. C. Brayshaw, a trained botanist, made the collections after the area had been selected as being eminently suitable for our purposes.

It must be made clear that variations such as appear in the following table are extreme and should not be expected when comparisons are made of the mineral content of trees growing over rocks with a composition more nearly approximating one another.

Lastly, it is only fair to point out that these data were not selected; all trees and lesser plants common to the two suites have been analyzed and the results are given in Table 4.

In only three cases out of the twenty given in Table 4 does the iron from the granodiorite sample run more than that taken from the conglomerate.

TABLE 4.

VARIATIONS IN THE IRON AND MANGANESE CONTENTS OF DIFFERENT SPECIES OF TREES AND LESSER PLANTS GROWING OVER DIFFERENT TYPES OF ROCK.

Species	Organ	Age	Granodiorite				Conglomerate			
			Fe	Mn	Fe:Mn	Ash %	Fe	Mn	Fe:Mn	Ash %
Pseudotsuga taxifolia (Douglas Fir)	Stem	1 year	60	130	.46	2.4	70	300	.23	2.1
Pseudotsuga taxifolia (Douglas Fir)	Stem	2 years	120	135	.89	2.2	120	200	.60	2.0
Pseudotsuga taxifolia (Douglas Fir)	Leaves	2 years	30	360	.08	4.1	80	900	.09	3.3
Tsuga heterophylla (Western Hemlock)	Stem	1 year	175	450	.39	1.95	625	375	1.80	3.05
Tsuga heterophylla (Western Hemlock)	Stem	2 years	350	375	.93	3.05	875	275	3.19	3.45
Abies grandis (Grand Fir)	Stem	1 year	80	300	.27	4.2	80	700	.11	3.65
Abies grandis (Grand Fir)	Stem	2 years	90	160	.56	3.5	375	625	.60	3.4
Pinus contorta (Lodgepole Pine)	Stem	2 years	110	60	1.83	1.5	210	35	6.00	1.4
Thuja plicata (Western Red Cedar)	Tips	2 years	60	125	.48	4.45	110	150	.73	4.45
Salix scouleriana (Willow)	Stem	1 year	75	100	.75	4.95	130	110	1.18	5.8
Alnus rubra (Red Alder)	Stem	1 year	110	110	1.00	4.4	40	150	.27	2.3
Acer macrophyllum (Broad Leaf Maple)	Stem	1 year	15	50	.30	3.85	25	175	.14	6.0
Acer circinatum (Vine Maple)	Stem	1 year	30	350	.09	4.2	135	375	.36	5.1
Acer glabrum (Rocky Mountain Maple)	Stem	1 year	65	110	.59	4.9	25	70	.36	3.2
Cornus Nuttallii (Flowering Dogwood)	Stem	1 year	35	15	2.33	5.6	75	15	5.00	5.3
Gaultheria shallon (Salal)	Stem	1 year	15	250	.06	2.9	40	650	.06	2.6
Vaccinium parvifolium (Red Huckleberry)	Stem	1 year	25	700	.04	4.65	100	1,500	.07	6.0
Arctostaphylos uva-ursi (Kinnikinnick)	Stem	1 year	50	75	.67	2.7	150	20	7.50	2.8
Pachystima myrsinites (False Box)	Stem	1 year	175	60	2.54	2.55	250	70	3.58	2.45
Corylus californica (Hazel)	Stem	1 year	70	150	.47	4.0	60	800	.07	6.75

In fifteen out of the twenty samples those from the conglomerate were likewise higher in manganese.

Much of British Columbia is mantled with glacial drift which will tend to obscure results when investigations are made of elements which are both abundant and widespread. Manganese and iron studies may well yield more encouraging results when undertaken in unglaciated areas. However, by making use of a suitable species of tree it may well be possible to trace specific formations through glacial over-burden.

During some of our earlier investigations we entertained the hope that there might be a reasonably narrow range which might be termed "normal" for the zinc and copper content of boughs. A glance at Table 4 shows that no such illusions are possible as far as iron and manganese are concerned. Only after many more investigations in areas which do contain "normal" amounts of iron and manganese will it be possible to determine "normal" contents for various species and organs under varying physiographic and climatic conditions.

The Presence of Ore.

In this section we are elaborating a previous paper (7) in which we discussed the anomalous zinc content found in some species of trees near the Sullivan Mine. We also gave some manganese analyses which indicated that this element might also be used to indicate anomalies suggestive of buried mineralization.

Since 1946 we have improved greatly our analytical techniques and have made many new analyses. The following table has been compiled on 1950–51 analyses of suites collected in 1946, when our collecting technique, judged by present standards, was somewhat crude. The method of collecting samples in 1946 has already been described (7) and consequently need not be discussed again. We believe that the results that follow would be bettered rather than worsened by the use of our newer collecting techniques.

A general consideration of the preceding table suggests that where there is evidence of anomalous zinc there tends also to be anomalous iron and manganese. However the variations of the zinc content of the Lodgepole Pine are even more noticeable than are the variations of the iron and manganese. Actually the Sullivan sphalerite only contains from ten to fifteen per cent of iron and considerably less than that amount of manganese, and consequently this result might have been expected as far as manganese is concerned. However, the presence of pyrrhotite, which is associated with sphalerite in the Sullivan ore, introduces a complicating factor which we are unable to evaluate, but which may explain the fact that fluctuations in the iron content of the Lodgepole Pine are greater than those of manganese.

In short, the presently available evidence suggests that, although in some areas iron and manganese anomalies may be useful in betraying buried mineralization, in the Sullivan area it would be more profitable to concentrate biogeochemical studies on zinc itself.

Pyrrhotite like magnetite lends itself to well known geophysical methods and for this reason alone biogeochemical methods would hardly be appropriate

in the vicinity of the Sullivan mine. However, in searching for an ore in which pyrrhotite or magnetite were absent, or where iron or manganese, or both, were abundant and the metal being sought present in minor quantities, it seems probable that biogeochemical anomalies in iron and manganese might well be

TABLE 5.

NORMAL AND ANOMALOUS IRON AND MANGANESE CONTENTS IN LODGEPOLE PINE BOUGHS.

(a) Three samples from the Sullivan Area but considered to be negative or normal ran:

Sample No.	Fe	Mn	Zn	Ash %
46.62	50	185	39	2.55
46.63	40	125	30	1.15
46.66	90	200	47	2.2
Total	180	510	116	
Average	60	170	39	

(b) In the Ymir area where there probably is a higher rainfall, indicated by the presence of more cedar, hemlock, and alder, the average of a hundred Lodgepole Pine tips of "normal" iron and manganese gave:

Fe 25 Mn 150

Remembering that further work may necessitate some modifications of our analyses it is, nevertheless, interesting to compare the results obtained from some positive Sullivan samples with the negative ones cited above.

(c) Groups of Anomalous Samples

Sample No.	Fe	Mn	Zn	Ash %	Ratio of iron, manganese and zinc relative to "normal"		
					Fe	Mn	Zn
Group No. 1.							
46.54	60	180	57	1.9			
46.56	110	270	60	1.7			
46.57	100	300	48	1.9			
46.58	130	180	46	1.8			
46.60	260	450	86	1.1			
	660	1,380	297	8.4	2.2	1.6	1.5
	132	276	59	1.7			
Group No. 3.							
46.01	20	280	360	2.2			
46.06	60	250	100	2.2			
46.15	120	550	90	2.2			
46.18	60	800	200	2.4			
46.20	120	900	140	2.5			
46.50	140	700	220	2.6			
46.52	300	250	170	2.5			
46.53	360	660	280	2.1			
	1,180	4,390	1,560	18.7	2.5	3.2	5.0
	147	549	195	2.3			

TABLE 5.—*Continued*

Sample No.	Fe	Mn	Zn	Ash %	Ratio of iron, manganese and zinc, relative to "normal"		
					Fe	Mn	Zn
Group No. 4 a.							
46.08	250	200	200	2.1			
46.12	80	280	200	1.6			
46.16	22	200	40	1.0			
46.22	10	150	90	2.4			
46.25	80	160	160	2.1			
46.26	60	200	110	1.8			
46.28	50	120	160	1.7			
46.43	80	180	54	1.7			
	630	1,490	1,014	14.4	1.3	1.1	3.3
	79	186	127	1.8			
Group No. 4 b.							
46.30	60	300	140	2.3			
46.33	65	130	640	2.2			
46.34	800	70	200	3.0			
46.35	150	450	220	2.2			
46.37	90	160	500	1.9			
46.39	110	400	170	2.2			
46.41	180	300	76	1.7			
	1,455	1,810	1,946	15.5	3.5	1.5	7.1
	208	259	278	2.2			
Group No. 5.							
46.44	160	300	60	1.9			
46.45	80	200	54	1.8			
46.47	80	30	28	.6			
46.48	100	250	74	1.8			
46.49	50	300	60	1.8			
	470	1,080	276	7.9	1.6	1.3	1.4
	94	216	55	1.6			

used in a search for ore. Some epithermal gold or silver deposits might well be sought for by means of manganese biogeochemical anomalies.

COMPARISON WITH CONCLUSIONS OF PREVIOUS WORKERS.

This field of research is vast. Consequently, it is not surprising to find that in general our results do not conflict with those obtained by previous workers who for the most part were exploring different aspects of this problem. Indeed, our conclusions appear largely to be in accord with those of others who have researched in this field.

Essentially our conclusions as to the organs that contain most iron and manganese, the genera of trees most capable of extracting or accumulating iron and manganese, and the soil conditions favoring extraction of these metals are in agreement with those of previous workers.

We have, however, succeeded in showing that these two elements are not always present in inverse ratios in suites of specimens. Under special circumstances a tree or particular organs of a tree may be high or low in both iron and manganese.

FUTURE WORK.

Future investigations in the biogeochemistry of iron and manganese may well follow two main lines. First, detailed studies of many species in many areas will be needed before normal contents can be established. Second, researches are needed in areas where iron or manganese may be expected to be a useful pathfinder, for example, in a district known to contain gold or silver ore accompanied by much iron or manganese, or both, but not by significant amounts of copper or zinc.

A possible field for fruitful investigation also lies in studying variations in the contents of various metals, including iron and manganese, in trees growing on flat and variously sloping grounds. We have not yet obtained enough data to justify any conclusions but we have ample evidence to suggest that this field should be explored.

CONCLUSIONS.

The biogeochemistry of iron and manganese is much more complex and not as likely to be of use in the search for ore as is that of copper and zinc. Nevertheless, iron and manganese do show anomalies which can be related to ore occurrences. In special circumstances, such as in a search for a particular type of ore, biogeochemical studies of iron and manganese may have a practical application. In specific cases the biogeochemistry of iron and manganese may be of value in mapping the contacts of geological formations covered by overburden.

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conclusions arrived at in this paper, by their patient cooperation and willingness to discuss our various problems have done much to assist in these preliminary biogeochemical investigations.

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MINERALIZATION RELATED TO GRANITIZATION.[1]

G. E. GOODSPEED.

ABSTRACT.

Mineralization in the form of small veinlets or disseminated sulphides is common to many regions of granitization. Zones of intense mineralization owe their localization to fracturing, shearing, or to rocks favorable to replacement. The large quartz veins of Cornucopia have been controlled by post-granitization shearing; the magnetite deposits of eastern Okanogan County, Washington, were formed by the replacement of limestone lenses adjacent to an area of syenitization.

The process of granitization envisages the transformation into granitic rocks of the material originally deposited in a geosynclinal prism. Such a process would bring about a regional redistribution of certain chemical elements. It should be emphasized that kaolinitic material so abundant in a sedimentary series contains about 14 percent water. The change of kaolinitic material to feldspars must drive off this water. Water so released by granitization can easily become the source of hydrothermal solutions that produce mineralization.

In some ore deposits the metallization is a direct concentration of metallic elements brought about by granitization, in others the source of these elements is probably from beneath a geosynclinal prism.

INTRODUCTION.

For over fifty years the hydrothermal theory of ore deposition was predicated upon the assumption that mineralizing solutions were released from igneous intrusions as the final stage of slowly crystallizing magmas. The validity of this assumption was clearly established in many areas where mineralization was proved to be genetically related to orthomagmatic intrusions. Laboratory experiments on water-rich silicate melts also provide many pertinent data regarding crystal formation in such systems.

The term *mineralization* is used here in a special sense to include minerals distinctly later in time of formation than that of the parent mass. Later metallization, the concentration of ore minerals, commonly follows mineralization, but may or may not be closely genetically related to it.

The popularity of the hydrothermal theory was such that any mass of crystalline rock, especially if of granitic composition, adjacent to an ore deposit, was considered to have crystallized from a magma in order to have been the source of hydrothermal solutions. However, within the past decade it has been shown by numerous workers in various parts of the world that many granitic masses can be the result of granitization; that is, they were formed by the transformation of pre-existing rock to granite, rather than by the crystallization of a magma. Because mineralization is common in many

[1] Presented at the April 1949 meeting of the Cordilleran Section of the Geological Society of America at Berkeley, California.

regions of granitization, the problem of its genetic relations is obvious and demands field and petrographic investigations for its solution. The question thus arises: Can granitization be a source for mineralizing emanations in some areas and the crystallization of magmas the source in others?

Among the many writers who became aware of this problem was J. A. Dunn (15) [2] who said, "For some years now, the replacement origin of certain granites has been in the foreground of discussion and, as a necessary corollary, certain accompaniments of magmation, such as ore liquids, will require reconsideration." Before presenting data in consideration of this question, it is necessary for purposes of comparison to review briefly the relationship of mineralization to orthomagmatic bodies.

MINERALIZATION RELATED TO ORTHOMAGMATIC BODIES.

Many field and petrographic data must be coordinated to prove the intrusive nature of a mass of crystalline rock (22). Some of these criteria are as follows: (a) The form of the body must be such as to be compatible with the hypothesis of mass flowage of magma whether by forcible injection or by a more passive invasion accomplished by block or piecemeal stoping. (b) Grain size becomes progressively larger from the outer cooling surface to the inward part of the intrusive mass. (c) A uniform pattern in the overall texture is common and the earlier formed minerals are generally subhedral with sharp boundaries. If phenocrysts are present, they are commonly euhedral. (d) When poikilitic textures are present, the included minerals usually exhibit sharp boundaries with the host mineral, have the shape of a pyrogenic mineral and a composition which is in physical chemical harmony with the magmatic derivation of the igneous rock. (e) The surrounding rocks exhibit those features typical of thermal metamorphism and their mineral content is largely, if not entirely, dependent upon their original composition. For example, impure limestones yield lime silicate hornfelses whereas argillaceous rocks produce cordierite hornfelses. The extent of a contact-metamorphic aureole may range from a few feet around laccoliths or small stocks to several thousand feet around batholithic masses. Heat from the magmatic mass has apparently been the dominant agent and in many cases there is no evidence of shearing or addition of material from the magma to the aureole. On a small scale these features of thermal metamorphism are associated with the laccoliths and stocks of the Little Belt Mountains of central Montana and on a much larger scale with the Boulder batholith of Montana and its surrounding stocks. Knopf (31) has recently given an excellent description of the contact-metamorphic aureole of the Marysville, Montana, stock.

It has been realized for many years that not all the minerals in an igneous rock have crystallized directly from a silicate melt, but that some have been formed at the final stages of crystallization from the volatile-rich residium of the magma. Later-formed deuteric minerals exhibit features quite different from the earlier pyrogenic minerals. They are distributed as fine aggregates (sericite or kaolinitic material) which have replaced the earlier minerals, or

[2] Numbers in parentheses refer to Bibliography at end of paper.

they form local segregations, or they develop along joints produced by the crystallization of a moving or static magmatic mass. When deuterically altered, the pyrogenic minerals are selectively replaced by minerals that have formed at lower temperatures and the chemical constituents that are released during the replacement processes form new minerals in the same vicinity or move to other parts of the intrusive body.

In his recent study of the monzonitic laccoliths near Cedar City, Utah, Mackin (36) has shown that hornblende and biotite in the deuterically altered interior below the quickly chilled peripheral zone become an aggregate of feldspar and quartz with a little residual magnetite leaving only a faint outline of the original mafics. Here, too, the earlier formed magnetite has disappeared, but the feldspars have not been altered. Mackin has also shown that the migration of iron explains the occurrence of magnetite in joint cracks as well as the large replacement iron ore bodies in the limestone adjacent to the intrusive.

Somewhat different effects were noted by the author in a diabasic sill (about 75 feet thick) near Morton, Washington (16). In the central part of this sill, the rock has a coarse diabasic texture and the pyrogenic minerals are essentially labradorite and augite. There is a small amount of interstitial altered glass and where the pyroxene is in juxtaposition with this glass, that part of the pyroxene is altered to an aggregate of calcite and chlorite. Plagioclase in the same position shows only incipient kaolinitization which pentrates slightly inward along cracks in the feldspars. Some of the carbonate has migrated and is segregated in small veinlets.

The mere geographical association of mineral deposits with intrusive masses does not necessarily mean a genetic relationship. Knopf (31) has shown that the deposition of the gold-silver veins associated with the Marysville, Montana, stock came long after the intrusion. In the Little Belt Mountains of Central Montana, there are numerous sills, laccoliths, dikes, and stocks ranging in composition from basic lamprophyres and shonkinite to syenite and granite porphyry. Various features such as the presence of corundum in many of these rocks, indicate the magmatic consanguinity of a petrographic province. Some replacement deposits of magnetite and hematite occur locally in limestone adjacent to some of the laccoliths; other hematitic and limonitic replacement deposits are not close to any intrusive. There are no magnetite deposits within the igneous bodies. Therefore, it would seem that the source of the hydrothermal solutions which formed these replacement magnetite deposits was a deep-seated basic magma.

Previously Bateman (6) had suggested: "The possibility that in certain types of iron-titanium-rich magmas, differentiation, perhaps influenced by volatiles and strong fluxes, results in an iron-rich residual magma that may give rise to such types of magmatic iron deposits as the Adirondack, Iron Mountain, Taberg, The Bushveld, perhaps Kiirunavaara, and also to platinum pipes and some chromite deposits."

From a theoretical standpoint, a magmatic intrusion may be considered to be essentially a closed system in which crystallization is effected principally by falling temperature. As pointed out by Niggli (40), the vapor tension of

a melt containing volatiles will reach its maximum when most of the nonvolatile constituents have crystallized and the temperature is relatively high. The vapor pressure will force some of the volatiles to move out of the confines of the magmatic chamber and thus form limited open systems. A recent paper by Bowen and Tuttle (9) gives an excellent discussion of the application of laboratory experiments with "wet" melts to the field occurrences of ultrabasic rocks.

The question of the amount of volatiles (chiefly water) which were present in a magma and which could become the source of hydrothermal solutions is most important. According to Ingersen (29), estimates vary from 1 to 50 percent, his own estimate being 3 percent. Because of the enormous amount of water required, Lindgren (34, p. 525) noted the difficulty of postulating basic magmas as a source for the Lake Superior copper deposits. Recently, Brown (10) has emphasized that very large volumes of water are necessary to produce the extensive mineralization present in some mining districts. He does not believe that a magma could contain enough water to produce such effects. This is one of the reasons why he rejects the hydrothermal theory of ore deposition, although he readily admits that at the locus of deposition water may have been an important factor.

In many districts where there is a clear genetic relationship between mineralization and orthomagmatic rocks, the overall extent of additive mineralization is limited, even though local concentration may form ore deposits. In contrast to this, the overall extent of such mineralization is very great in many other districts where granitized rocks occur in geosynclinal structures. Since in these districts the field and petrographic evidence strongly indicates that the mineralization was effected chiefly by hydrothermal solutions, the amount of water required must have been very large. If granitic magma cannot provide sufficient water for extensive additive mineralization, the question arises, how could granite formed by metamorphism satisfy the water requirement? Before considering this question it is appropriate to review briefly some of the processes and features incident to granitization.

SALIENT FEATURES OF GRANITIZATION.

In the latter part of the nineteenth century some geologists rejected the established theory that all granites were of igneous origin and instead advocated a metamorphic origin for most granites. As one of the principal arguments Le Conte (33) in his text, Elements of Geology (p. 225), states: "In many localities in mountain-regions, and nowhere better than in the Sierras of California, every stage of gradation may be observed between clayey sandstones and gneiss, and between gneiss and granite. So perfect is this gradation, that it is impossible to draw sharply the distinction. Even geologists who believe that granite is the primitive rock have been compelled to admit that there is also a metamorphic granite, scarcely distinguishable from primitive granite."

About the same time, however, the systematic studies of rock specimens and thin sections by many famous petrographers were so detailed and con-

vincing that the assumption of magmatic origin of granitic rocks completely overshadowed any ideas of metamorphic origin. The latter concepts were forgotten for nearly half a century. Within the past three decades they have been revived, for the most part independently, by geologists who encountered field evidence that could not be explained adequately by the magmatic hypothesis. A complete list of these geologists would be a long one and would include the following: Quirke (41), Sederholm (49), Wegmann (53), Anderson, G. H. (2), Goodspeed (17), Backlund (4), Reynolds (46), Read (44, 45), Holmes (28), Barth (5), Misch (39) and Ramberg (42). It is noteworthy that very recently two structural geologists, Bucher (11) and Stille (50), consider the concept of granitization to be compatible with modern theories of megatectonic geology. Bucher says: "The complexity of the crust beneath the continents is the result of major crustal folding, i.e., the formation of upbowed welts and downbowed furrows, that filled with sediments. Compression of these belts drew out the sediment-filled furrows into roots of mountains and set in motion the physical and chemical processes that transformed part of the sediments into metamorphic rocks and ultimately into granite." Stille makes the following statement: "Dass Granite durch Migmatisierung ("Granitization") d. h. Gesteinsbestandes unter Waerme-und Staffzufuhr, entstehen koennen, ist nicht mehr zu bezweifeln." A few years previously Umbgrove (52), in his book "The Pulse of the Earth" (p. 72), had this to say about the extent of granitization: "Probably most, if not all, of the granite batholiths are not of primary igneous origin but originated as secondary or palingenetic products of granitization."

In the field, bodies of granitized rocks superificially resemble those of igneous origin, but their form is not necessarily compatible with a mechanism of injection and mass flowage of magma. Some masses contain long thin undisturbed relics of the country rock and others have contacts that exhibit a marked gradation from the wall rock into the granitic rock. In granitized bodies, even in those of small size, chilled borders or a coarsening of the grain size inward is not apparent. Inclusions in granitic rock have commonly been called xenoliths, implying fragments of the wall rock engulfed by the magma; and this implication has formed the basis for the hypothesis of magmatic stoping. However, inclusions in some granitic bodies show no evidence of engulfment by a magma; on the contrary, their definite alignment with the structure of the wall rock and their microcrystalloblastic textures clearly indicate that they are merely relics which have escaped granitization. Such relics have been called skialiths (23).

In contrast to the aureoles of thermally metamorphosed rock surrounding an igneous body, the metamorphic rocks adjacent to a granitized mass exhibit the features of dynamo-thermal and additive metamorphism. In many field occurrences, the gradation from metamorphic to granitic rocks clearly indicates that granitization represents an end stage of progressive metamorphism. The transition of schists to gneisses to migmatites on a regional scale is in striking contrast to the thermally metamorphosed aureoles surrounding orthomagmatic masses.

In areas of granitization, many dikes exhibit cogent field evidence that they have been formed by metasomatic replacement rather than by the crystallization of a silicate melt. Such dikes have been called replacement dikes by the author (18). This evidence includes: projections of the wall rock into the dike; wall rock septa; undisturbed skialiths, structural relations such as lack of offset which are incompatible with the mechanism of dilation; crystalloblastic microtextures and structures. Replacement dikes in various stages of formation are common in many areas. Early stages are represented by closely spaced parallel feldspathic bands, in later stages the dikes still contain much relict material and in the final stages relict material is recrystallized or completely obliterated. These stages indicate a mechanism of progressive metasomatism controlled by recurrent fracturing accompanied by a rise in temperature.

Although the megascopic features of igneous and granitized rocks are similar, the microtextures and structures of granitized rock are commonly quite different from those of orthomagmatic rocks. Standard collections cannot be used for such comparisons because many rocks in these suites have been labelled igneous although their mode of origin is really doubtful. In contrast to the euhedral tendency of pyrogenic minerals and the uniform texture pattern of igneous rocks, granitized rocks have a haphazard, uneven seriate texture where many crystals tend to be anhedral with interlocking crenulated borders. Larger crystals, which resemble phenocrysts, commonly contain inclusions of metamorphic minerals giving a moth-eaten or sieve-like appearance in thin section. If the metamorphic structure is preserved in relict form in the large crystals, it is said to be helizitic. The inclusion of quartz grains in a calcic plagioclase is incompatible with the physical chemical laws pertaining to the fractional crystallization of silicate melts. It is therefore more plausible to suggest that such crystals are porphyroblasts or metacrysts and that they are in many cases the result of reaction of hot intergranular solutions with the solid material of the original rock. This interpretation is substantiated by the presence of crystals in various stages of development from an early amoeba-like form filled with included material to a later subhedral form with but little included material. If the original rock were an argillaceous sediment, this material would be essentially kaolinitic in composition or would consist of metamorphic minerals derived from argillaceous material. The transformation of a sedimentary rock like an arkose with a composition and grain size similar to a granitic rock is a relatively simple matter. Recently Coombs (14) has clearly shown the various stages of such a transformation.

During the granitization of argillaceous sediments, the transformation of kaolinite to feldspar involves a liberation of 14 percent of combined water. The importance of the release of water during feldspathization of argillaceous sediments has, in connection with the balance of volume, been emphasized by Misch (39). In contrast to the increase in volatiles in a closed magmatic system consequent upon crystallization due to lowering of temperatures, this water is added to the mobile solutions of an open system of metamorphism which is subjected first to a rise and then to a decrease in temperature.

Water content of rocks was emphasized by Dunn (15). "The original water content of the rocks originally present over a considerable depth of crust would be enormous and if this water on being driven off from the lower part of the sial is pictured as becoming concentrated within a critical narrow zone, moving upward with the geo-isotherms, the rocks within that zone would become saturated with slow-moving solutions, and may become changed in composition, completely recrystallized, and perhaps even "fused," before the greater part of the water passed on." He used the term *diabrochormorphism* for this recrystallization with or without change in composition.

Many other geochemical rearrangements may take place incident to crystalloblastic growth. Elements not used in the growing crystal will be expelled or segregated. For example, some quartz porphyroblasts in the initial stage exhibit chloritic rims and some feldspar porphyroblasts show small segregations of magnetite. The differential absorption of calcium by a plagioclase porphyroblast may be an explanation for the development of zoning (17). It is also probable that within an individual crystal, or in rock masses under deep-seated conditions, solid diffusion is a factor influencing crystalloblastic growth (Reynolds, 47). If, as stated by Bugge (12), this is usually an exothemal process, then this additional heat will tend to increase the rate of crystalloblastic growth.

Although the effects of metamorphic differentiation can be noted with regard to single porphyroblasts, they are much more evident in relation to crystalloblastic aggregates. Feldspathic replacement dikes formed in an iron-rich hornfels commonly show borders rich in hornblende. This means that released iron was in such excess that it could not be entirely carried away by the solutions forming the dike, but in part was forced to migrate directly into the walls. Similar features have been noted in replacement breccias, in orbicular rocks of metamorphic origin, and in small blocklike forms of crystalloblastic growth. These examples of crystalloblastic growth lend themselves to detailed petrographic study, especially if they are small enough to be contained on a large ($3\frac{1}{4} \times 4$ inch) thin section. The making of such sections has recently been described by Lang and Smedes (32).

In the field, it is noticeable that certain masses of granitized rock are locally surrounded by wall rocks enriched in minerals high in iron, magnesium and calcium. This basification constitutes the well-known basic front and is attributed to a geochemical migration (47). The term "front" was first used by Wegmann (53), and as in military parlance, either a mobile front or a static front is possible. During the advancing stages of granitization, an earlier formed basic front would later be granitized and furnish an increased amount of basic elements to extend the basic front further. The migration and precipitation of elements is controlled by many factors: Two important ones are tectonic fracturing and the physical-chemical character of the "invaded" rocks. Depending upon the variability of these factors, a basic front may or may not be formed, may be extended, or may be localized.

Locally at Cornucopia, Oregon, relict minerals and textures clearly show that previous to basification, the wall rock was a hornfels of sedimentary origin. Basic elements were expelled from the adjacent granodioritic mass during the

period of advancing granitization. Cataclastic brecciated zones in this basic front testify to the presence of tectonic forces, and the partial granitization associated with these zones is indicative of the advance of granitization.

RHEOMORPHIC DIKES, MOBILIZATION OF GRANITIZED MATERIAL AND NEOMAGMAS.

Recent studies of some of the granitic and porphyry dikes at Cornucopia have shown that they have many of the field features of ordinary igneous dilation dikes, but lack chilled borders, and have in part gradational contacts with the wall rocks. One porphyry dike which transects a breccia with numerous inclusions in various stages of transformation, locally has contacts in which the metasomatic matrix of the breccia grades into the dike. Under the microscope, this dike shows distinct flow structure; the larger plagioclase crystals are of the same composition as the porphyroblasts in the matrix of the breccia and commonly exhibit relics of crystalloblastic features. Contacts of other dikes show what appears to have been flowage of statically granitized hornfels into the dikes. Swirls of minute flakes of biotite streamlined around porphyroblasts in the wall rocks near the contacts indicate that the flow direction was toward the dikes. The mobilization of metamorphosed material forms a new magma (neomagma) which, in this case, did not pass through the stage of a liquid silicate melt. Flowage of metasomatized material can be considered one of the processes of rheomorphism as defined by Backlund (4); therefore, dikes of this type can be called rheomorphic dikes.

Mobilization implies movement of metasomatized material by plastic flowage. The material can be in any stage of transformation from partially granitized replacement breccias and migmas with dominant amounts of non-granitized relics to large completely granitized masses. Rocks resulting from rheomorphism (to use this term in a restricted sense) exhibit initial crystalloblastic textures and later, clearer, more homogenous crystals which have separated from the intergranular solutions of highly mobile material. Flow structures are pronounced and intrusive relationships common although relict features may be present.

Neomagmas may consist of completely metamorphosed material ranging from mobile grout-like consistency to a more homogeneous liquid or even a melt which flows easily, has intrusive relationships to the country rock and is sufficiently fluid to permit an abundance of crystals to form by fractional crystallization during flowage and later cooling stages. Earlier crystalloblastic textures are still discernible in neomagmatic rocks. Although flow structures and later formed crystals are similar to features of orthomagmatic rocks, the presence of earlier minerals exhibiting crystalloblastic features and the absence of well formed earlier pyrogenic minerals, their relics, or original orthomagmatic textures serve to distinguish neomagmatic rocks from truly magmatic rocks. Under very high temperature a neomagma might become a liquid silicate melt, but even then earlier non-pyrogenic relics could give a clue as to the origin of the neomagma. Such cases are similar to some examples of local ultra optalic metamorphism. Probably certain rheomorphic dikes furnish the best illustrations of neomagmatic rocks.

MINERALIZATION RELATED TO GRANITIZATION.

Many metamorphic rocks adjacent to areas of granitization commonly contain disseminated pyrite. At Cornucopia, the pyritization of hornfelses is sufficiently extensive to produce, on weathering, dark brown surfaces. Althought some of the pyrite may well have been an original constituent, it is quite probable that both iron and sulphur were expelled during the quartz-feldspathic transformation of argillaceous rocks incident to an advancing stage of granitization.

A greater concentration of scattered grains of pyrite and magnetite occurs locally in a 500-foot zone of basicified hornfels exposed in the low-level Coulter adit at Cornucopia, between higher grade hornfelses and granodioritic rock. Garnet, diopside, epidote, hornblende and biotite are common minerals in this zone and occur in irregular veinlike masses or in roughly parallel bands. Interspersed with these are irregular feldspathized areas and thin elongated relics of the original schistose hornfels. Although magnetite and pyrite are distributed locally throughout this basic zone, it appears that a greater concentration of finely granular magnetite is associated with the amphibolitic and biotitic bands while coarsely granular pyrite and magnetite favor the garnetized areas.

A much greater concentration of magnetite occurs on Buckhorn Mountain in eastern Okanogan of north-central Washington, where relatively large masses of magnetite have replaced limestone. Associated with the magnetite are lime silicates, dominantly garnet and epidote, and later sulphides chiefly pyrrhotite. These bodies of magnetite are adjacent to syenite which exhibits field and petrographic features indicative of metasomatic replacement. Since a part of the rock subjected to syenitization is amphibolitic in composition, the migration of a considerable amount of iron is to be expected. Chemically reactive material in the form of lenses of limestone would cause the precipitation of the iron as magnetite. The magnetite and the lime silicates appear to be formed contemporaneously, indicating that this metallization took place during the progressive stage of the syenitization, while the later sulphides, formed at lower temperature, may represent a retrogressive stage.

On the island of Unst, one of the Shetlands in Britain, small spessartite bodies intrude chlorite phyllites. The spessartite contains numerous irregular quartz-chlorite-pyrite lenses and veinlets which Read (43) suggests have resulted from processes of metamorphic differentiation and were segregated from the spessartite during dislocation metamorphism. Recently Chapman (13) has given a detailed description of quartz veins formed by metamorphic differentiation of aluminous schists. He suggests that differential movement and slipping along bedding surfaces caused the more soluble substances (quartz and feldspar) to be filterpressed out of the schist into low pressure loci at the crests and troughs of folds and along joint cracks.

At Cornucopia, Oregon, the retrogressive stage is responsible for the formation of many alteration bands and veinlets transecting areas of granitization. In smaller granitized bodies, their local origin can easily be demonstrated. A small replacement dike occurring in the basic zone exposed by the low-level adit at Cornucopia has an irregular overall fabric and consists almost entirely of

turbid untwinned feldspar and quartz with an average grain size of 2 to 3 mm. The quartz shows replacement textures with respect to the feldspar. Occasional grains of amphibole with epidote are no doubt relics from the walls. There is no diminution in grain size on the borders of the dike; instead there is a distinct crystalloblastic penetration of the feldspar and quartz into the walls. A few grains of magnetite and pyrite are scattered throughout the dike but several grains of these minerals are concentrated in a small prong of the

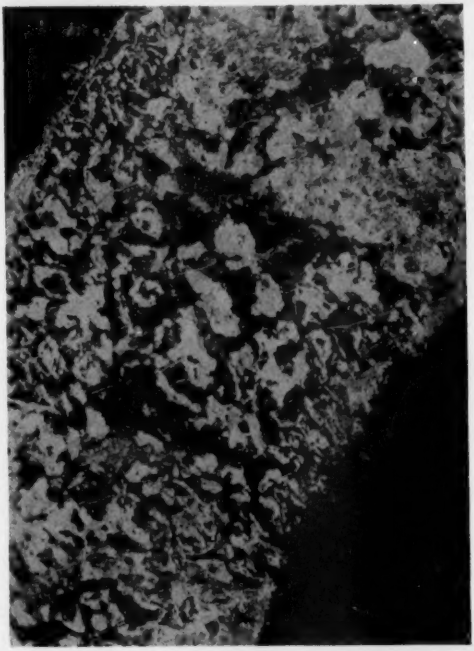

FIG. 1. Photographic enlargement of part of a large thin section of a small (15 mm in width) replacement dike. Note the swarm of minute quartz, epidote, calcite veinlets transecting the crystalloblastic aggregate of turbid feldspar and quartz.

country rock penetrating the dike. A most interesting feature of this dike is that for a distance of 8.5 cm along its strike (within the boundaries of a large thin section), there are over 40 minute veinlets that transect the dike at approximately 45°. These veinlets which have an average width of 0.05 mm are filled with quartz, epidote, and calcite. Most of them do not extend beyond the borders of the dike (Fig. 1).

Some replacement dikes are transected at right angles by veinlets of quartz,

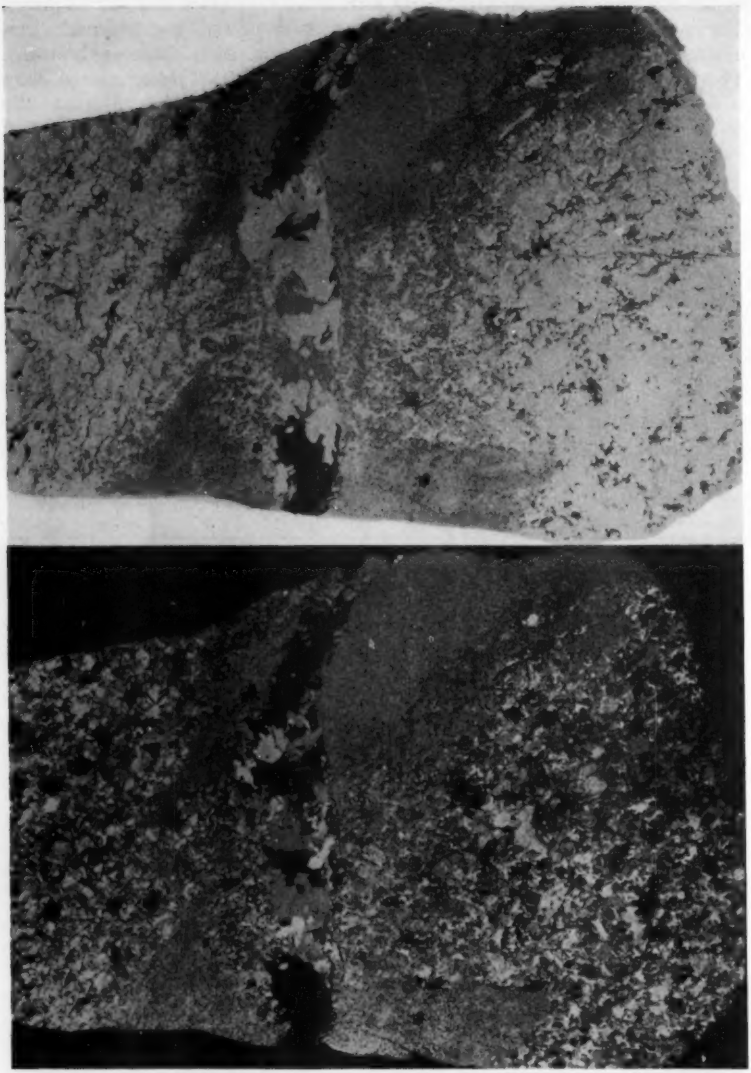

FIG. 2. Photograph of a large thin section showing a quartz, chlorite, calcite, sericite veinlet transecting a replacement breccia. In this veinlet chlorite is predominant where the veinlet cuts altered hornfels fragments in the breccia. Upper, ordinary light; lower, x-nicols.

with chlorite, calcite, epidote, and muscovite. These veinlets, which are essentially confined to the dikes, are generally bordered by irregular alteration zones in which the original white plagioclases of the dikes have been changed to pink kaolinized feldspars, locally partially seriticized, and the mafics altered to chlorite and epidote. The veinlets vary from a fraction of a millimeter up to 10 mm in width. Minerals other than quartz are generally irregularly distributed although in some veinlets transecting replacement breccias, chlorite and sericite appear to be concentrated in that part of the veinlet which cuts small inclusions (skialiths) of seriticized hornfels (Fig. 2). Another veinlet which is about 3 mm wide and transects a 3-inch granodioritic replacement dike displays a double terminated quartz crystal surrounded by calcite which, along the borders, is filled with aligned inclusions. Therefore, it appears that the mechanism of formation for this veinlet was filling followed by replacement (Fig. 3).

FIG. 3. Photomicrograph of a part of a 3 mm veinlet of quartz and calcite transecting a hornblendic skialith in a 3-inch granodioritic replacement dike. The double terminated quartz crystal in the center of the veinlet is indicative of filling as a mechanism of formation while the aligned inclusions in the calcite along the borders suggests later replacement. x-nicols.

Another 2-foot nearly vertical leucocratic granitic dike transecting hornfels in the low-level tunnel at Cornucopia contains a series of nearly horizontal quartz veinlets. The dike is medium-grained, consisting chiefly of plagioclase and quartz. Under the microscope, the texture is seen to have an uneven pattern with dominant oligoclase (An 27), subordinate orthoclase and quartz

ranging in size from 0.5 mm to over 1.5 mm and surrounded by a fine-grained aggregate (0.06 in average size) of quartz and feldspar. Marked sieve structure and crenulated borders characterize the feldspars. The larger quartz anhedra exhibit relict aggregate structure. Ragged flakes of muscovite, plumose sericitic aggregates, idiomorphic pyrite, and calcite are present. The latter mineral appears in part to be contemporaneous with feldspar as is shown by its sharp boundaries against clear unaltered feldspar. The horizontal veinlets, spaced about 2 feet apart, are thinly lenticular in shape with a maximum width of 2 inches in the dike and taper out into the hornfels on either side of the dike to a distance of about 1 foot. A thin border of sericitic alteration is present along the veinlets in the dike, but in the hornfels wall rock alteration is not apparent. The veinlets contain some irregular aggregates of pyrite.

Replacement dikes are developed in an open system characterized by rising temperature. At the time of maximum crystalloblastic growth, however, the system becomes essentially a closed one. At this time, the local front of granitization has become stationary and the rock inside that front is readjusting itself to physical-chemical conditions in an attempt to reach equilibrium. This closed system persists during the subsequent period of falling temperature to a time when fractures, due either to contractional or to tectonic forces, will form.

Therefore, it might be expected that lower temperature minerals would be formed in a replacement dike during the retrogressive stage of falling temperature in a manner similar to the formation of deuteric minerals in an igneous dike. It is also plausible that these minerals could collect in veinlets. In other words, solutions released during the retrogressive stage of a replacement dike tend to alter the earlier formed minerals and to seep into any available fractures. Since these veinlets are essentially confined to the dikes and either do not extend at all into the wall rock or extend only a relatively short distance from the dike, and since their mineral composition appears to be controlled by the composition of the dike, it is clear that they were not formed by extraneous solutions.

Many of the replacement breccias and migmatites at Cornucopia are transected by incipient alteration veinlets which consist chiefly of kaolinitic material or contain disseminated carbonate, chlorite, magnetite or pyrite. Some of the small blocklike masses of granodioritic rock have small veinlets limited to the loci of crystalloblastic growth. The mode of origin of these veinlets justifies the same interpretation as that given above for replacement dikes. Some veinlets associated with a replacement aplite breccia (21) follow tensional joints and others cataclastic shear zones.

As previously mentioned, some of the porphyry and granitic dikes at Cornucopia have structural and textural features of igneous rocks but have crystalloblastic microtextures indicative of metasomatism. These have been called rheomorphic dikes. Many of these dikes are transected by horizontal veinlets of quartz, chlorite, carbonate and epidote. In some of the dikes, the veinlets are 8 to 10 inches apart and are bordered by alteration bands from ¼ to 1 inch in width. Since these veinlets are essentially confined to the dikes, it appears that the residual volatile constituents of the neomagma

FIG. 4. Photograph of a specimen from a small, nearly vertical porphyry (rheomorphic) dike in hornfels showing two almost horizontal alteration bands. Note that upper band penetrates only $\frac{3}{4}$ of an inch into the hornfels wall rock and that the lower band does not extend through an inclusion in the dike.

in the dike seeped into transecting fractures which were probably formed as contraction joints following the consolidation of the dikes. The mode of origin of these veinlets is similar to that of some of the later veinlets in igneous rocks (Fig. 4).

In the case of small granitized masses, such as dikes, it is easily demonstrated that any resulting mineralization is confined to the masses themselves

and that they are the source of the mineralization. Hence it may be inferred that the granitization of larger masses such as stocks would produce similar features on a larger scale. It is also to be expected that solutions from a large granitized mass could easily penetrate into the surrounding country rock. In a recent study of the tungsten mineralization at the Ima mine in the east central part of Idaho, Anderson (1) has given an excellent description of a granitized mass. He concludes that "The granitization, which locally has converted quartzite to granite, apparently represents an early super-intense phase of wall-rock alteration that formed an essential part of the mineralizing process." He is also of the opinion that the relationship of granitization to mineralization may be much more common than has been previously recognized.

At Cornucopia, where there is ample proof that the large adjacent granodioritic body is a product of postorogenic granitization, thousands of later aplitic pegmatitic and quartz veins and veinlets transect the granitic rock. These range from a fraction of an inch to a few inches in width and while commonly several feet apart are much more closely spaced in some parts of the granitic area, with only a few inches between them. On weathered surfaces they appear as small ridges. They display a wide variation in texture from fine-grained to aplitic to coarse pegmatitic. This variation is commonly seen in a single vein where the mineral composition varies from dominantly feldspathic to dominantly quartzose. For example, a vein 5.5 cm in width shows on one wall a quartzose band 6 mm wide, then a 2 mm feldspathic band, next a quartzose band 7 mm in width. A feldspathic band, about 9 mm wide, partially replaced by quartz separates this from a band of coarse-grained (1 cm anhedra) quartz 2.5 cm wide. Along the opposite wall is a 1.3 cm band composed of fine-grained oligoclase (0.3 mm) with a border of larger (2 mm) plagioclase crystals that have their longer axes at right angles to the wall, suggesting a rough comb structure. Beyond this border in the granodioritic rock, sericitization extends for about 2 mm while next to the quartzose band there is no alteration (Fig. 5).

However, some veinlets are bordered by alteration bands that are several times the width of the veinlets. In these zones of alteration, petrographic examination indicates that there has been a gradual replacement of the original minerals of the wall rock by alteration products which are chiefly aggregates of sericite, carbonate and quartz where the walls are of granodioritic composition, and sericite, chlorite, and carbonate where the walls are hornfels. In the altered granodiorite, it is not uncommon to find one side of a feldspar crystal next to a minute veinlet completely altered while the farther side is relatively fresh. The aggregate of alteration minerals, however, merge from one crystal to another so that only the faintest outlines of the original feldspars are discernible. The original quartz appears to have been attacked and partly replaced by quartz that has either been formed as a released mineral of the alteration reactions, or has been introduced with the hydrothermal solutions. In his studies of the Mother Lode veins of California, Knopf (30) suggested that most of their quartz had been derived from the wall rocks as a product of alteration reactions.

The large gold-quartz veins at Cornucopia are similar in some respects to the small veinlets, but differ markedly from them in others. They have bordering alteration zones with gradational contacts and other features suggestive of replacement although locally some parts of the veins show evidence of filling. However, in contrast to the small veinlets, parts of the large veins show a multiplicity of slickensides and slipping planes and in thin section marked microbrecciation (Fig. 6). This minute fracturing of the earlier quartz furnished channels for the later metallizing solutions. Quartz exhibiting microbrecciation has been called cataclastic to distinguish it from the nonbrecciated or aclastic quartz (20).

The larger veins occupy narrow zones of intense shearing. Some transect the irregular contact of the granitic and the hornfelsic rock; others are entirely within the granitic rock. Since at Cornucopia there is no evidence of the existence of a contemporaneous orthomagmatic mass and since there is cogent evidence in smaller bodies that mineralization is directly related

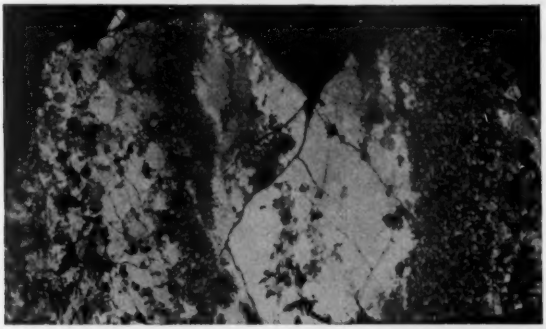

FIG. 5. Photograph of a large thin section of an aplitic (fine-grained) and quartzose pegmatitic veinlet. The contacts between the fine-grained feldspathic band and the quartz indicate that this mineral has replaced the earlier aplitic material.

to granitization, it is plausible to infer a similar relationship with regard to the more extensive mineralization. The later basalt (Tertiary) dikes which transect the region are not hydrothermally altered, although deuteric alteration is present in some of the diabase dikes of similar age. As might be expected, some of these dikes follow the upper portions of some of the veins, and have caused local optalic metamorphism. Here part of the pyrite in the veins has been converted into pyrrhotite by loss of sulphur.

The main granodioritic mass of the Wallowa Mountains batholith, with an areal exposure of over 100 square miles, lies approximately 8 miles north of Cornucopia, Oregon. Numerous mineralized zones occur along the borders of this batholithic mass where it is in contact with crystalline limestone, but to date no productive ore deposits have been found notwithstanding the prevalence of postgranitic shearing. Although according to some earlier

interpretations this mass of crystalline rock has been considered to be orthomagmatic, more recent field and petrographic studies have indicated a possibility that it is a product of granitization.

In any large area of granitization water and other elements such as iron and magnesium migrate outward from the locus of intense metamorphism.

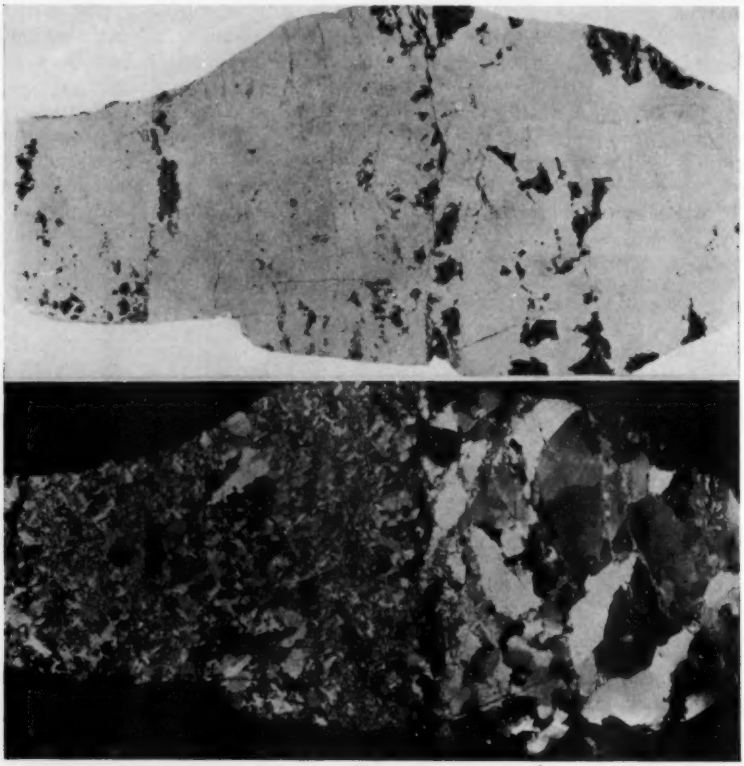

FIG. 6. Photograph of a large thin section of one of the large gold-quartz veins from Cornucopia. Note the areas of aclastic and cataclastic quartz and the relation of metallization to microbrecciation. Upper, ordinary light; lower, x-nicols.

Therefore, the surrounding rocks, especially the more permeable ones, become enriched in these elements and widspread disseminated pyrite might be expected. An emplacement by static granitization of a relatively small stock in such rocks would lead to further geochemical rearrangements which if favorable structural features prevailed could culminate in loci of mineralization and early metallization.

At Cornucopia, the gold-quartz veins are grouped within the southeastern part of an irregular stocklike granodioritic mass which is exposed for about 4 miles in a northwest-southeast direction and 3 miles in a northeast-southwest direction. They appear to be structurally related to the major tectonic features belonging to the late Mesozoic orogeny of the region, and their general strike (N 40° E) is roughly parallel to anticlinal and synclinal axes in the older rocks (48). The larger veins follow westerly dipping shear planes. Some of the smaller veins are controlled by the easterly dipping complementary fissures. All the veins are irregularly lenticular, in some places very narrow, practically gouge seams, and at others several feet wide. The five major veins are spaced from 1,500 to 2,500 feet apart and the two which have been most productive transect a large-scale metamorphic migmatite zone replete with replacement breccias, replacement dikes, relict masses, skialiths, irregular granitized bodies, and other features characteristic of granitization. These two veins commonly exhibit an echelon-like offset of 20 to 30 feet every 500 or 1,000 feet along the strike. One of the veins has been explored to a depth of nearly 3,000 feet on the dip and the other to about 2,000 feet on the dip.

All field and petrographic data (19) point definitely to the assumption that the Cornucopia veins have been formed by hydrothermal solutions which were active in the retrogressive stage of the metamorphism following the granitization. There is no evidence of an early magmatic mass which might have been a source for the hydrothermal solutions, or which might have produced structures favorable to vein formation. Mercury has been found, by spectrographic analyses, to occur in some of the veins, whereas not a trace of this element has yet been found either in the hornfelses or granitic rocks, or in the much later diabase and basalt dikes. This indicates that part of the metallization may have come from a deep source. In a discussion of ore and rock lead, Holmes (26, 27) postulated that the source of ore lead may have been from beneath the sial and the sima. Billingsley and Locke (8) have noted that major ore districts are clustered at structural nodes formed by superimposed orogenic movements, intersecting fracture lines or persistent deep-seated breaks. More recently, from geochemical data, White (55) has suggested a subcrustal source for sulphide ores and emphasizes a structural rather than a genetic relation between intrusives and ore deposits.

The formation of a residual magma unusually rich in ore-forming elements is questioned by Djalma Gunaraes (25) who points out that the concentration of rare earths within sediments is similar to that in pegmatites whereas according to a magmatic differentiation hypothesis, pegmatites should contain a much greater concentration. In lieu of the magmatic hypothesis, he suggests that "granitization of considerable sedimentary massifs brings about, therefore, the dissolution of a great many metallic elements lying in the sediments, and their upward migration."

With regard to the source of ore minerals, Dunn (15) suggests that if they were deposited in the early crust they might enter magma formed from any part of the crust or might be transferred to a higher zone by solutions previous to the actual formation of a magma. It is his opinion that the initial

distribution of metals may have played an important role in the present-day localization of metallogenic provinces in later rocks. He also states that regenerated magmas forming at the base of the crust may tap subcrustal sources of metals in the sima.

In a paper entitled "The Mechanics of Orogeny," Griggs (24) presented the hypothesis that geosynclines were formed by the dragging down of the sial and sima by very slow-moving (pseudo-plastic) flow of subcrustal convection currents which would complete a cycle of acceleration and deceleration in a period of 50 million years. Uplift would take place when the subcrustal currents ceased to move, due to the buoyancy of lighter sialic material seeking isostatic equilibrium. In a recent paper, Longwell (35) presents an excellent analysis of tectonic theory based on his studies of the Basin Ranges of Western United States. He says that the primary agent of crustal deformation is a supreme mystery, but also states that "Advocates of convection currents in the body of the earth will urge this concept as the most promising to explain

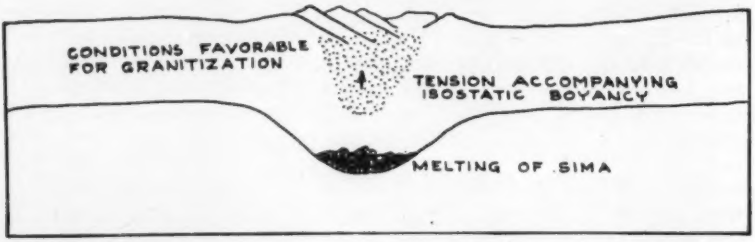

FIG. 7. End of convection current cycle—period of emergence. Buoyant rise of thickened crust aided by melting of mountain root. Middle part of the geosynclinal mass now under tension thus affording favorable conditions for granitization and later metallization by rising emanations. Modified after Griggs, A Theory of Mountain Building: Am. Jour. Sci., vol. 237, no. 9.

the slow but insistent eastward march of Cordilleran orogeny. This suggestion seems as good as any in this no-man's land of geologic thought." It is possible that future structural evidence and seismological data will shed more light on this fundamental question.

From the standpoint of economic geology, it is of interest to note, in view of the above hypothesis, that the formation of magmas at the root of the geosyncline is postulated. Tensional conditions accompanying isostatic bouyancy would favor their upward extension. However, it would certainly be expected that tenuous emanations would rise more easily than magma, and that these emanations would be able to saturate and granitize some of the rocks of the geosynclinal prism (Fig. 7).

The granitized core of a folded geosyncline would thus become essentially a structurally isotropic mass. Later fracturing consequent upon further uplift would tend to be localized in the more brittle mineralized zones along the periphery or adjacent to a strong rock mass. Intense metallization of

these zones would depend, in part, upon whether or not there was connection with a profound fracture zone through which ascending deep-seated emanations could carry up the heavy elements from a subcrustal region. Billingsley and Locke (8) emphasize the significance of the strength of masses of gneiss or granite in allowing ore-bearing channels to extend from depths to surface. A similar idea is expressed by Armstrong (3) in his discussion of the mercury belt which extends from southeast of Fort S. James, B. C., 150 miles northwest to Omineca River. He states: "This fault zone follows the western border of the Hogem batholith for at least 150 miles and it is quite probable that the batholith, because of its relative rigidity, acted as a buffer against later regional stresses, thereby localizing the fault zone along the border." He also says that "no genetic relationship is apparent between the mercury deposits and any nearby volcanic or intrusive rocks."

Profound fracturing has been indicated by seismological studies of deep-focus earthquakes. In a recent paper, Benioff (7) has given detailed evidence with regard to both shallow and deep-focus earthquakes of the Tonga Kermadec sequences and the South American sequences. Regarding the former sequence, he says: "Since the curve for the shallow sequence bears no relationship to that of the deep sequence, it may be concluded that there is no effective mechanical coupling between the two layers in which these sequences have their origins. Thus the boundary which separates them at a depth of approximately 70 km must be a surface of profound discontinuity in the physical state or composition of the rock." The deep South American fault surface had an interval of 5½ years without an earthquake during which time strain accumulated so that when the fault did give way it generated two great earthquakes which brought the total elastic rebound movement to the value determined by the initial line. In this respect, Benioff states: "Thus for a period of 5½ years, the rock of this fault maintained a linear elastic strain without flow at a depth of 650 km." It is possible that future geophysical research will furnish data applicable to ore genesis.

CONCLUSIONS.

The most spectacular occurrences of granitic rocks formed by granitization are to be found in folded geosynclines (37). Many thousands of cubic miles of material are deposited in a thick geosynclinal prism; and the material has the widest range of chemical composition. The transformation of this material into granitic rock involves not only a vast chemical rearrangement (51) but also a radical physical change. In a thick mass of sediments, the amount of water both connate and combined, may well be measured in cubic miles. The mobilization and release of this water by granitization forms an abundant source for hydrothermal solutions.

Locally within the geosynclinal prisms argillaceous material would on recrystallization yield a greater amount of water than a more anhydrous rock like limestone. It is therefore possible that this is one factor which may have a bearing on the question of why some parts of a granitized mass show little mineralization. However, probably the most important factors are the

presence of granitized satelitic stocks and favorable structures. It is also possible that the type of geosyncline—for example, ensialic or ensimatic (54)—may have an important influence on the related later mineralization. Mineralized zones are commonly the loci for later metallization and, although in some cases metallization is directly related to granitization, in others a source beneath the geosyncline may be indicated.

Ore deposits directly related to igneous intrusions are formed at the final stages of cooling of the magmatic body. The elements forming the deposits as well as the vehicle for transporting these elements came essentially from the magma. Hence in an igneous petrographic province, one might expect a certain regularity in the zones of mineralization. On the other hand, in a large area of granitization, the relatively gradual transformation of many rock types of diverse composition involves geochemical rearrangements which, combined with the varying amounts of volatiles, could give rise to many kinds of related mineralization.

It is possible, however, that either an intrusive body or a granitized mass may be merely a structural control for later metallization. In this respect relatively simple structures of an igneous intrusion are in marked contrast to the complex structural features of large or small granitized masses with their irregular contacts and included relict material.

In either case, the later and perhaps much later metallization may be due to the presence of profound fractures which provide access for emanations from deeper magmas, potential magmas, or even from subcrustal sources.

UNIVERSITY OF WASHINGTON,
SEATTLE, WASHINGTON,
Sept. 16, 1951.

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MINOR ELEMENTS IN ARKANSAS BAUXITE.[1]

MACKENZIE GORDON, JR. AND K. J. MURATA.

ABSTRACT.

A study of the minor elements in Arkansas bauxite has revealed some striking relationships between their concentration in the parent nepheline syenite rocks as compared with their concentration in the bauxite. The ratios of concentration, in general, follow a pattern predicted by Goldschmidt (3),[2] based upon the ionic radius and ionic charge of each element present. In the Arkansas deposits, Mg, Ca, Ba, La, and Sr were depleted during the change from nepheline syenite to bauxite. The average concentration of Pb remained the same in the samples tested. Y, Mn, Be, V, Sc, Ti, and Zr were concentrated, but not as much as Al; while Mo, Nb (Cb), Ga, Cu, and Cr were concentrated more than Al. Niobium (columbium) apparently is found in sufficient quantities to warrant search for methods to extract it commercially as a by-product of alumina plants.

INTRODUCTION.

THE U. S. Geological Survey recently completed a study of the minor elements present in Arkansas bauxite, as well as those present in the nepheline syenite rocks from which the bauxite and related weathering products were derived. One aspect of this investigation constitutes the subject of this paper.

The study of the minor elements is one of the phases of a much larger investigation of the Arkansas bauxite deposits that has been in progress since late in 1941. From April 1942 to June 1945 an extensive Federal drilling program was carried on jointly by the Geological Survey and the Bureau of Mines, with very helpful cooperation by all the operating mining companies. Besides bringing to light hitherto undiscovered bauxite ore bodies aggregating approximately 20 million tons of ore in place, this work yielded a wealth of geologic data, chemical analyses, and core and pit samples of many of the Arkansas deposits. The Bureau of Mines has published logs and chemical analyses of the drill holes (6). A report on the geology of the Arkansas bauxite region has been completed and awaits publication as a professional paper of the Geological Survey (5).

The bauxite deposits are in Pulaski and Saline Counties, just south of the city of Little Rock, and extend discontinuously for about 20 miles to the southwest. Three samples of nepheline syenite and 14 of bauxite and bauxitic clay were selected for study. These samples were collected from both counties and from several different types of deposits.

[1] Publication authorized by the Director, U. S. Geological Survey.
[2] Numbers in parentheses refer to Bibliography at end of paper.

METHOD AND RESULTS OF SPECTROGRAPHIC ANALYSIS.

The spectrographic analysis was made under the following conditions:

Excitation: 220-volt ballasted d-c arc, run at 15.5 amperes. Arc image focussed on the slit at × 5.5 magnification, and light from the central 2-mm portion allowed to enter the spectrograph.

Spectrograph: Jarrell-Ash model 70–15–e with dispersion of 5A/mm in the first order.

Wavelength range covered: 2230–4730A in the first order.

Electrodes: National Carbon Company's high-purity ¼"-diameter graphite rods, with thin-walled cavity as described by Myers (7). Used as the anode.

Plate: Eastman III–O, developed at 20° C for 5 minutes in Eastman DK–50 developer.

Plate calibration: Method of Dieke and Crosswhite (2). Iron lines present in spectra of a quartz-microcline mixture containing 1 percent Fe_2O_3 (matrix of comparison standards) were used.

Microphotometer: Applied Research Laboratories' model 2250.

Analytical curves were established by means of several sets of standards containing known concentrations of various elements in a matrix consisting of 6 parts of quartz, 4 parts of microcline, and 0.1 part of Fe_2O_3, 25-mg portions being arced to completion. No internal standard was used.

The nepheline syenite samples were ground in agate mortars to pass 150-mesh silk bolting cloth and mixed with one-half of their weight of pure quartz powder. The bauxites were first ignited at 900° C (loss on ignition noted), ground to minus 150 mesh and mixed with equal weight of a powder containing 95 percent pure quartz and 5 percent Na_2CO_3. For both the nepheline syenites and the bauxites, the aim in preparing the samples was to make them correspond approximately in composition to the standards with respect to silica, alumina, and alkalis.

Twenty-five-milligram portions of each sample were exposed in duplicate on two separate plates. For any given element, the mean on each plate did not deviate by more than ±10 percent of the mean of both duplicates. The accuracy of the general method had been tested through previous analyses of igneous rocks that had been chemically analyzed for some of the minor elements like Cu, Co, Ni, V, Cr, and Zr. In general, the spectrographic values lie within ±20 percent of the best chemical values for igneous rocks.

The National Bureau of Standards bauxite no. 69 served as a rough check on the accuracy of the bauxite analyses with respect to Ti, Zr, V, Cr, Ca, Mg, Mn, and Cu. There was reasonable agreement for all these elements excepting Cu, and it is believed that the certificate value for this element is about 5 times too high.[3] The values for niobium in bauxites were also checked by preparing a special set of standards with the NBS bauxite no. 69 (Nb free) as the matrix.

The maximum, minimum, and average amounts of the minor elements de-

[3] We are indebted to Hy Almond, Chemist, U. S. Geological Survey, for check analyses for copper in this sample by the dithizone method.

TABLE 1.

SPECTROGRAPHIC DETERMINATION OF MINOR ELEMENTS IN NEPHELINE SYENITE AND IN BAUXITE AND BAUXITIC CLAY SAMPLES FROM ARKANSAS.

Element	Nepheline syenite (3 samples)			Bauxite and bauxitic clay (14 samples)		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Ti	.68[a]	.3[a]	.51[a]	1.8	.2	1.06
Zr	.07	.03	.050	.2	.08	.13
Mn	.1	.09	.097	.4	.05	.12
Ca	1.47[a]	.65[a]	1.01[a]	.3	.03	.12
Nb	.02	.009	.013	.1	.02	.050
Mg	.57[a]	.29[a]	.38[a]	.1	.002	.037
Sr	.04	.02	.027	.09	.0004	.019
Ba	.2	.003	.071	.1	.0009	.017
Y	.02	.009	.013	.04	.004	.015
Cr	.0002	—	.0001	.03	.002	.011
La	.04	.02	.030	.03	—	.010
V	.006	.003	.0047	.02	.004	.0092
Ga	.002	.002	.0020	.01	.005	.0086
B	—	—	—	.009	—	.0031
Mo	.001	—	.00057	.005	—	.0018
Cu	.0005	—	.00017	.003	—	.0014
Sc	.0005	—	.00033	.001	.0004	.00069
Pb	.002	—	.00067	.007	—	.00067
Ni	—	—	—	.005	—	.00064
Be	.0002	.0001	.00017	.002	—	.00022
Co	—	—	—	.002	—	.00014

K. J. Murata, analyst. Figures in the table are in parts of one percent. Looked for but not found in any of the samples: As, Sb, Bi, In, Tl, Sn, Ag, Zn, Ge, Ta, P.

[a] Calculated from chemical analyses.

Dash means that the element was not detected.

tected in the 3 samples of nepheline syenite and the 14 samples of bauxite and the bauxitic clay are given in Table 1. These amounts are shown in parts of one percent.

MINOR ELEMENTS IN DIFFERENT TYPES OF BAUXITE DEPOSITS.

Gordon, Tracey, and Ellis (4) have divided the bauxite deposits of Arkansas into four principal types depending essentially upon their relationships to the surrounding rocks. These types may be summarized as follows, and their general field relations are shown in Figure 1.

Type I. Residual deposits on the higher slopes of buried nepheline syenite hills are separated from fresh nepheline syenite by kaolinitic clay that, adjacent to the bauxite, appears massive or fragmental. The lower part of the bauxite generally preserves the granitic texture of the original rock, and the upper part is concretionary.

Type II. Deposits formed in a colluvial apron that mantles the lower slopes of the same buried hills are located roughly along the buried edge of sediments of the Midway group. The bauxite has a thin lower zone locally preserving clay textures and absent in some places, a thick concretionary zone

above, and commonly a siliceous hardcap up slope. These deposits grade into a surrounding kaolinitic envelope. Their deposition was contemporaneous with that of a lower unit of lignite, gray clay, and sand of Wilcox age farther down slope.

Type III. Alluvial deposits, composed of stratified, sorted, and cross-bedded pebbles, pisolites, and grains of bauxite, overlie and fill channels in Type II bodies and tongue into sediments of the lower unit of the Wilcox group.

Type IV. Alluvial deposits, mostly bauxite boulder beds, overlie either residual bauxite deposits or sediments of the lower unit of the Wilcox group. These alluvial deposits tongue into younger sediments, particularly as the basal conglomerate of the dark chocolate-brown clay and sand that forms the upper unit of the Wilcox group and unconformably overlies the lignite, gray clay, and sand of the lower unit.

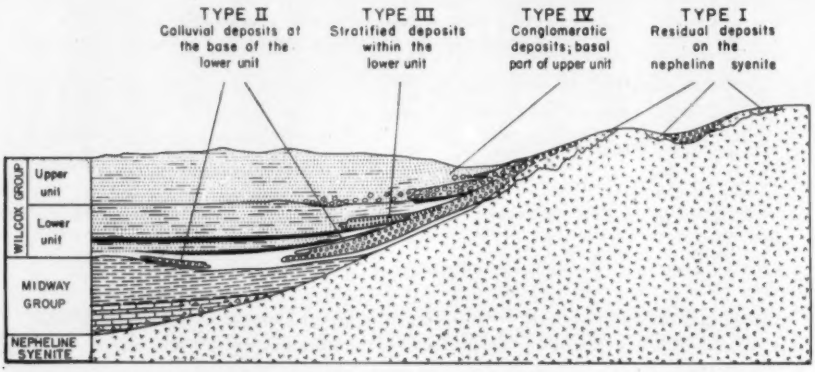

FIG. 1. Diagrammatic section of the principal types of deposits in the Arkansas bauxite region.

Of the 14 samples of bauxite and bauxitic clay studied, three came from mines in Type I deposits in Saline County, two of them from granitic-textured bauxite blocks and one from red pisolitic bauxite. Seven samples were selected from Type II deposits, of which four came from a single drill hole in Saline County, the specimens in descending order being one each of siliceous bauxite hardcap, of crudely pisolitic bauxite, of bauxitic underclay, and of kaolinitic underclay. A specimen of pisolitic bauxite from a nearby drill hole and one each of pisolitic bauxite hard cap and of crudely pisolitic bauxite from Pulaski County drill holes complete the roster of Type II samples. Three Type III samples were determined, from two mines in Pulaski County and one in Saline County. The only Type IV sample studied came from a transported block of bauxite rubble in a Saline County mine.

The average determinations for each type of deposit are given in Table 2. These represent a further breakdown of the averages for all the bauxite and bauxitic clay samples shown in Table 1, seventh column.

Altogether 21 minor elements were noted in the bauxitic rocks, 18 of which were detected also in the parent igneous rock. Boron apparently is limited to deposits within the Wilcox group (Type II, Type III, and Type IV deposits); its source may have been connate water in the marine sediments of the Midway group, as boron is found in sea water. Cobalt and nickel were found only in alluvial (Type III) deposits. Elements not listed in Tables 1

TABLE 2.

AVERAGES OF SPECTROGRAPHIC DETERMINATIONS OF MINOR ELEMENTS IN BAUXITE AND BAUXITIC CLAY FROM THE FOUR TYPES OF ARKANSAS DEPOSITS.

Element	Bauxite deposits			
	Type I (3 samples)	Type II (7 samples)	Type III (3 samples)	Type IV (1 sample)
Ti	.73	1.1	1.0	1.8
Zr	.12	.12	.13	.2
Mn	.083	.17	.040	.05
Ca	.033	.11	.20	.2
Nb	.050	.050	.040	.08
Mg	.0053	.050	.037	.09
Sr	.0035	.010	.053	.03
Ba	.0013	.0030	.060	.04
Y	.0057	.020	.012	.02
Cr	.0043	.0089	.018	.02
La	.012	.0096	.0067	.02
V	.0060	.0077	.016	.01
Ga	.0063	.0060	.0093	.008
B	—	.0029	.0070	.002
Mo	.0010	.0016	.0030	.002
Cu	.0013	.0019	.00067	.001
Sc	.00053	.00074	.00077	.0006
Pb	.00033	.00067	.00090	.001
Ni	—	—	.0030	—
Be	—	.000057	.00090	—
Co	—	—	.00067	—

K. J. Murata, analyst. Figures in the table are in parts of one percent.
Dash means that the element was not detected.

and 2 but known to be major or minor constituents either of the nepheline syenite, or of the bauxite, or both, are aluminum, ferric and ferrous iron, carbon, oxygen, sulfur, and chlorine.

Phosphorus, shown by chemical analysis to average 0.17 percent P_2O_5 in the nepheline syenite samples, was not detected spectrographically either in the nepheline syenite samples or in the bauxitic rock samples. Small amounts are probably present in the bauxite but cannot be detected spectrographically as the limit of sensitivity for this element is about 0.5 percent P_2O_5. Arsenic, which is known to occur in very small amounts in the bauxite, likewise was not detected by means of the spectrograph.

CONCENTRATION OF MINOR ELEMENTS IN THE BAUXITE.

The relative concentrations in Arkansas bauxite for 18 elements, as well as aluminum, found to be common to the nepheline syenite and the bauxitic rocks are shown in Table 3. This is expressed as the ratio of the concentration of each element in the bauxitic rocks to its concentration in the nepheline syenite rocks. Concentration ratios are given for each of the four types of deposits as well as for the average of all the bauxitic samples. They are derived from Tables 1 and 2 by dividing the average content of each element in the bauxitic samples by its average content in the nepheline syenite samples. The elements are arranged in Table 3 according to the values of these quotients, in descending order. Those with values greater than one were concentrated by the weathering processes; those with values less than one were depleted. The average values for aluminum were computed from chemical analyses of the specimens where available, and are shown on Table 3 to indicate which elements are in greater or less concentration than aluminum.

The averages for all the bauxitic samples, in the third column of Table 3, show that Mg, Ca, Ba, La, and Sr were depleted during the weathering process or processes that changed nepheline syenite to bauxite in Arkansas. The average concentration of Pb appears to have remained the same, but examination of additional samples might alter the results slightly. Y, Mn, Be, V, Sc, Ti, and Zr were concentrated but not as much as Al; while Mo, Nb (Cb), Ga, Cu, and Cr were concentrated more than Al.

The results in Table 3 also indicate that there was further concentration of many of the concentrated minor elements as the deposits were reworked and subjected to more weathering or transportation, or both. Too few samples, however, have been examined to make any sweeping generalizations.

The behavior of the minor elements during weathering to bauxite has been discussed by Goldschmidt (3). His very interesting statement in an article pointing out the relation to ionic potential of the behavior of various chemical elements under certain geochemical processes was called to our attention by M. Fleischer of the Geological Survey, and is as follows:

". . . besides beryllium and gallium which follow aluminium, the elements titanium, zirconium, tin, and quinquevalent niobium are found to be concentrated in bauxite, together with aluminum hydroxide, and the factor of concentration is about the same as that of alumina, being as a rule about 4–5-fold as compared with their mother rock.* In some cases vanadium also is somewhat concentrated in the bauxites. The tervalent elements with somewhat lower ionic potential, such as the lanthanides, yttrium, and even scandium, are as a rule not concentrated in typical bauxites, because their lower ionic potential permits their removal in aqueous solution."

Goldschmidt obviously was referring to European bauxites, to judge from his remark about the 4- to 5-fold concentration of alumina, which would be possible only in bauxite containing alumina largely in the monohydrate form. Nevertheless, the present study of Arkansas bauxite in which alumina is

*I may mention that the alkali aluminate solutions of the Baeyer process for making alumina are a potential source for very large quantities of gallium.

TABLE 3.

CONCENTRATION RATIOS OF MINOR ELEMENTS IN BAUXITE AND BAUXITIC CLAY AS COMPARED TO NEPHELINE SYENITE.

	Elements	Ratios of concentration				
		In bauxite, all types	In bauxite deposits			
			Type I	Type II	Type III	Type IV
		B/A	C/A	D/A	E/A	F/A
Concentrated >Al	Cr	100	40	90	180	200
	Cu	8	8	11	4	6
	Ga	4.3	3.2	3.0	4.7	4
	Nb	3.8	3.8	3.8	3.1	6
			3.0			
	Mo	3.2	1.8	2.8	5.3	4
	Al	2.7		2.4	3.0?	
Concentrated <Al	Zr	2.6	2.4	2.4	2.6	4
	Ti	2.1	1.4	2.1	2.0	3
						2.9
	Sc	2.1	1.6	2.2	2.3	2
	V	2.0	1.3	1.6	3.4	4
	Be	1.3		.3	5.3	
	Mn	1.2	.9	1.8	.4	.5
	Y	1.2	.4	1.5	.9	1.5
	Pb	1.0	.5	1.0	1.3	1.5
Depleted	Sr	.7	.1	.4	2.0	1
	La	.3	.4	.3	.2	.7
	Ba	.2	.02	.04	.8	.6
	Ca	.1	.03	.1	.2	.2
	Mg	.1	.01	.1	.1	.2

A represents concentration in nepheline syenite samples.
B represents concentration in bauxite and bauxitic clay samples.
C, D, E, F represent concentration in samples from Type I, II, III, and IV deposits, respectively.

concentrated 2½ to 3 times is, on the whole, an excellent verification of the statement quoted above.

BEHAVIOR OF ELEMENTS RELATED TO IONIC POTENTIAL.

The value of ionic potential as a concept to explain many different chemical reactions was first pointed out by Cartledge (1). Later it was applied by Goldschmidt specifically to geochemical processes. Ionic potential is not a definite property of chemical elements. It is, rather, the ratio of their ionic charge to their ionic radius. Those with the same or similar ratios are likely to behave similarly.

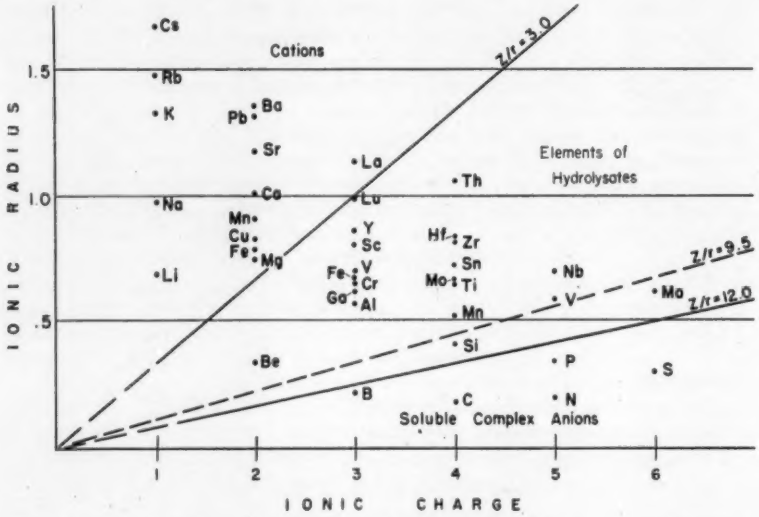

FIG. 2. Grouping of certain elements according to their ionic radii and charges.

A number of the elements are plotted on the graph (Fig. 2) to show the relation of their ionic radius to ionic charge. This figure is modified after a similar one by Goldschmidt (3). The elements have been replotted here according to the values for ionic radius given in the seventh edition of Dana's System of Mineralogy (8).

The field of elements can be divided into three principal groups, separated by lines of equal ionic potential, Z/r. These are the diagonal lines that radiate from the point of origin. The first of the solid diagonal lines shown on Figure 2 represents an ionic potential of 3.0. Elements of low ionic potential lie to the left of this line, many of which form basic oxides. These remain in true ionic solution in the processes of weathering and transportation, thus are carried off and depleted. Substances between the two solid diagonal lines,

the second line representing an ionic potential of 12.0, are amphoteric elements that form both basic and acid oxides. According to Goldschmidt (3) they are precipitated by hydrolysis, their ions being associated with hydroxyl radicals from aqueous solutions. A dashed diagonal line has been drawn in the figure to indicate an ionic potential of 9.5 because this value is believed to represent more closely the upper limit of the elements concentrated in bauxites. The elements with higher ionic potential form complex anions containing oxygen and are usually soluble and remain in true ionic solution.

For purposes of comparing the results obtained from Arkansas bauxite with the theoretical expectations, the experimental data for all the bauxitic

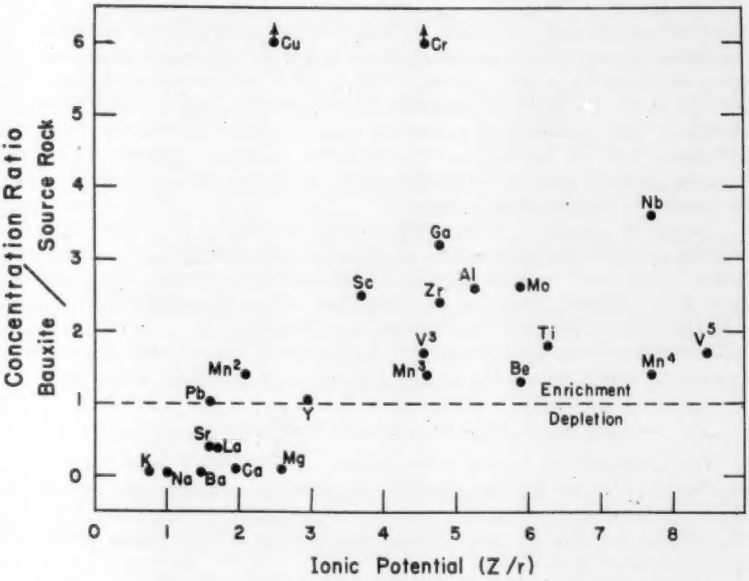

FIG. 3. Concentration of certain elements in Arkansas bauxite, grouped according to ionic potential.

samples, taken from the third column in Table 3, are plotted graphically in Figure 3. In this diagram the vertical axis represents the ratio of concentration of the minor and several major elements in the bauxite as compared with their concentration in the nepheline syenite; along the horizontal are plotted ionic potentials up to 9 units. As can readily be seen, the elements with ionic potentials between 3 and 9 have all been enriched by the weathering process; alkalis and rare earths with ionic potentials less than 3 have been depleted (except for Cu and Pb, discussed later). The fact that bivalent manganese falls above the line and below 3 does not necessarily disagree with the

theoretical considerations, but indicates rather that the manganese is present mostly in the trivalent or quadrivalent forms.

There is not complete agreement, however, between the theoretical behavior of the elements and their concentration as actually determined. A comparison of Figure 2 with Figure 3 and Table 3 shows that there are discrepancies that involve principally beryllium, copper, chromium, and lead.

Beryllium, which theoretically should be concentrated along with aluminum in bauxite, actually has a very erratic distribution in the Arkansas rocks as determined from our samples. It was detected only in four samples—two siliceous hardcaps and two bauxite gravels. Its apparent average concentration ratio of 1.3 in the 14 bauxitic samples is due mostly to the inclusion, in the average, of one unusually high content recorded in one bauxite gravel. In most of the bauxite, beryllium is absent or less concentrated than in the nepheline syenite. Ionic potential alone, therefore, apparently does not explain the behavior of this element. Nor could a satisfactory explanation be arrived at for the high concentration of chromium recorded in the bauxitic samples. The spectrograph is sensitive down to about .0001 percent both for chromium and for beryllium. It is possible, however, that the nepheline syenites sampled were not entirely typical for the region, particularly as far as chromium content is concerned.

Copper is present in the nepheline syenite samples in very small amounts and theoretically should have been depleted during weathering. It actually is 4 to 11 times more concentrated in the bauxitic rocks. Lead, which should have been depleted, remained in about the same concentration as in the original rock. This relative concentration of both elements may have been brought about by events subsequent to bauxitization, such as the burial of the deposits by late Eocene sediments accompanied by a rise of the water table.

BAUXITE AS A POSSIBLE SOURCE OF SOME MINOR ELEMENTS.

The statement of Goldschmidt, quoted earlier, called attention to the possibility of recovering considerable quantities of gallium from the alkali aluminate solutions of the Bayer process. A commercial method for recovering gallium has recently been devised and is being used in Bayer plants of the Aluminum Corporation of America.

Discovery of a significant concentration of niobium (columbium) in the bauxite from Arkansas is one of the interesting results of the present spectrographic study. Rankama (9) already has pointed out that the concentration of this element is far greater in nepheline syenites than in other igneous rocks and also that in hydrolysates the highest Nb (Cb) contents are found in bauxites and in laterites. In Arkansas the bauxite, derived from nepheline syenite, has an average Nb (Cb) content of roughly .05 percent. This was determined from our 14 bauxite and bauxitic clay samples, supplemented by six additional, mostly of pisolitic bauxite from other localities in Pulaski and Saline Counties. Niobium probably is largely in combination with several titanium-bearing minerals that are found in the heavy mineral fraction of the bauxite, such as anatase, ilmenite, and rutile (9).

Niobium (columbium) is one of the metals used principally in high-temperature steels and has attained high strategic importance in recent months. The large tonnage of Arkansas bauxite mined annually and processed through modified Bayer alumina plants could be a significant source of niobium if the rather difficult chemical problems involved in the separation of this metal from titanium could be solved. If only half the amount now lost could be recovered it would constitute an important contribution to American industry.

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WASHINGTON 25, D. C.,
Sept. 17, 1951.

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THE GEOCHEMISTRY OF THE ORES OF FRANKLIN, NEW JERSEY.*

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ABSTRACT.

It is suggested that the ores at Franklin and Sterling are pyrometasomatic deposits formed in the Franklin Limestone, at some distance from the unknown igneous source of the ore-forming fluid. The general classes of skarn minerals developed by contact metamorphism (contact metasomatism in Barrell's sense of the term)—spinels, garnets, pyroxenes, epidotes, micas, olivines, and melilites—all are present in the deposits. These minerals are, however, unique in their high content of Mn^{+2} and Zn^{+2} and their relatively small amounts of Fe^{+2} and Mg^{+2}. The explanation advanced for this peculiar situation is that, in the source magma of the ore-forming fluid involved, an unusual abundance of Mn^{+3} resulted in the oxidation of most of the Fe^{+2}, which normally would have entered the ore fluid in that form, to Fe^{+3} and the concomitant reduction of much Mn^{+3} to Mn^{+2}. This oxidation of ferrous to ferric ion resulted in an uncommonly high acceptance of magnesium ion in the dark silicates of the crystallizing source magma and almost entirely eliminated Mg^{+2} from the ore fluid. The unusual scarcity of ferrous and magnesium ions in the ore fluid forced Zn^{+2} and Mn^{+2} to neutralize in large part those various contact mineral anions which are found in normal contact deposits combined with Fe^{+2} and Mg^{+2}. The lack of Cu^{+2} is thought to have been caused by its proxying for ferrous iron in the minerals of the original source magma and the paucity of Pb^{+2} by the difficulty of the large lead ion in entering and neutralizing any of the variety of anions available.

INTRODUCTION.

THE ore deposits at Franklin and Sterling in Sussex County, New Jersey first attracted attention before 1730 (1, p. 14).[1] Through the 200-odd years since their mineral worth was first suspected, countless mineralogists and geologists have visited the deposits, collected specimens of the unique mineral assemblage, and written and published discussions of the origin of the ore bodies, the printed length of which often varied inversely with the duration of the visit. It is, therefore, with some hesitancy that I enter the arena as my actual acquaintance with Franklin is slight, but such unique deposits almost certainly must have a unique explanation and what follows has that virtue at least.

In Palache's (1, pp. 2–14 and 130) monumental work on Franklin-Sterling mineralogy, he lists 289 titles in a bibliography running from 1810–1935, inclusive. From this impressive background of ideas, Palache summarized (1, pp. 23–24) five hypotheses which had been advanced by various authors,

* "Contribution of the Divisions of Geology and Mineral Economics, The Pennsylvania State College."

[1] Numbers in parentheses refer to Bibliography at end of paper.

including himself, and concludes that his own, calling for the metamorphism of a mixed deposit of oxidized ores of zinc, iron, and manganese, is most logical. Since that time Pinger (2, pp. 84–87) has advanced cogent arguments against Palache's theory and has discussed further the various other hypotheses mentioned by Palache. Pinger concludes that "the only hypothesis of origin that fulfills the observed conditions is a replacement of favorable horizons in the folded structures by a primary oxide ore." Pinger declines to speculate on the chemistry and mechanics of transportation and emplacement which is much to be regretted for no geologist has had more or better opportunity to observe the Franklin-Sterling ores and none is more capable of a sound contribution to the problem.

THE FRANKLIN ORES—A PYROMETASOMATIC DEPOSIT.

Pinger's concept of the Franklin deposits as primary oxide ore, however, is a distinct contribution to the solving of the problem of their genesis and in this paper I shall attempt to build from that foundation. If these ores are primary as Pinger contends (and what I have seen of them certainly convinces me that they are) they must, from the assemblage of high temperature ore and gangue minerals developed, have been formed under conditions of high temperature and pressure, at least several thousand feet beneath the then existing surface. The deposits were classified by Lindgren (3, pp. 737–739) as pyrometasomatic[2] and if it is kept in mind that the deposits are not at or near any known igneous contact, such a classification is satisfactory. As Loughlin and Behre (4, p. 47) pointed out, the distinction between hypothermal and pyrometasomatic (contact metamorphic) deposits is in the rocks in which they are formed; the solutions from which the two types of deposits are derived are essentially similar. The Franklin deposits, then, can be strictly termed "hypothermal in calcareous rocks" or "pyrometasomatic not at an igneous contact" without doing violence to the Lindgren scheme of classification.

The justice of classing the Franklin ores as pyrometasomatic is further demonstrated by comparing them, for example, to the deposits at French Creek in Eastern Pennsylvania (5). The French Creek ores are in a Precambrian white marble similar to, if not the same as, the Franklin (or White) Limestone at Franklin. There is, of course, a great diversity in the mineral suites but the general setting and the occurrence of the ore minerals is essentially the same in the two deposits. French Creek is a normal magnetite contact-metamorphic ore body—normal in its silicate and ore mineral content and in its relation to the igneous rock from which the ore-forming fluids were derived. Franklin is an unusual contact-metamorphic deposit—unusual in its mineral suite and in its position definitely away from contact with any possible source rock for the ore solutions.

[2] In this paper I have used "pyrometasomatic" and "contact metamorphic" interchangeably as adjectives to modify such terms as "ore body" or "mineral deposit" but have qualified both by indicating whether the deposit is truly at an igneous contact or away from it. Actually, in the strict sense of Barrell and Bateman, essentially all the deposits and minerals discussed are "contact metasomatic."

Ideally it would be desirable to explain both of the anomalous conditions that obtain at Franklin—lack of immediately adjacent igneous source rock and the strange mineral suite. As to the first peculiarity I have little to contribute except to remark that the igneous source rocks cannot have been the pegmatites because pegmatite is lacking at Sterling and often is considerably removed from ore at Franklin. I am in agreement with Pinger that the ores are later than the pegmatites and I do not believe that they were in anyway responsible for the ore. While I think that some of the unique Franklin minerals are the result of the reaction of the ore-forming fluid with pegmatitic skarn, much of the skarn is found around ore which is not spatially associated with pegmatite at all. In other words, much, if not most, of the skarn and the peculiar minerals it contains was the result of the reaction between the White Limestone (and what relatively few impurities it may have contained) and the ore-forming fluid and of nothing else. That the pegmatites were related to the ore-forming fluid in their ultimate source, however, is indicated by the notable amounts of manganese in pegmatite skarn well removed from any appreciable quantity of ore.

Even granting that a number of the mineral species at Franklin were developed by alteration of pegmatite skarn minerals by the ore fluid, the three principal ore minerals, willemite, franklinite, and zincite, and many of the gangue minerals have been produced without any contribution from the pegmatites and represent a definite, though peculiar, type of pyrometasomatism of the Franklin Limestone. The problem posed by these strange contact-metamorphic minerals is to explain why such unusual spinels, silicates, and simple oxides formed instead of the normal contact spinels, silicates, and oxides of pyrometasomatic deposits such as that at French Creek.

As Ries and Bowen (6, p. 552) demonstrated, the order of deposition of the ore minerals at Franklin was first the silicates tephroite and willemite, which were introduced contemporaneously or nearly so, followed by the spinel, franklinite, which replaced mainly the limestone but also the silicates slightly as well. The oxide zincite was somewhat later than franklinite and replaced calcite and silicates and filled fractures in franklinite (which fractures probably contained calcite before the zincite was emplaced). This is the general order of formation of silicate gangue and spinel and oxide ore minerals in the average contact deposit and fits (allowance being made for the abnormal composition of these minerals) with the classification given the ores by Lindgren. The paragenesis of the less common and less well studied silicates at Franklin has never been worked out in detail but apparently varies somewhat from one area of the mine to another. Actually the sequence of emplacement may not be too complicated because the relations of the gangue silicates to each other and to the ore minerals have been considerably obscured by the insistance of the earlier workers, principally Palache and Ries and Bowen, that the pegmatites came in after the ore minerals and that all of the non-ore silicates not in hydrothermal veins were the result of the interaction of solutions given off by the crystallizing pegmatites and the already emplaced ore minerals. The disproving of this theory

by Pinger and his colleagues at Franklin has made possible a much more reasonable interpretation of the reasons for the development of the Franklin mineral assemblage. Instead it now appears that the bulk of the skarn is the result of the reaction of the ore-forming fluid with the calcite of the White Limestone and that locally an even more complex skarn was developed when the ore fluids encountered the skarn around the earlier pegmatites.

THE PYROMETASOMATIC MINERALS AT FRANKLIN.

Spinels.—If Franklin is an unusual pyrometasomatic deposit, then it is important to indicate exactly how it differs from a normal deposit of the class. The main difference and the one I believe to be the ultimate cause of all the peculiar minerals developed is the relative abundance of manganic ion and the concomitant paucity of ferrous iron in the deposit and, presumably, in the ore fluid from which it was formed. While ferrous iron is minor in amount in the Franklin minerals, iron in the ferric state is the principal cation in franklinite, a spinel, which is the dominant ore mineral—43% of the average ore according to Palache (1, p. 17). In a normal pyrometasomatic deposit, the $Fe_2O_4^{-2}$ anion is in balance with Fe^{+2} and ferrous ferrite (magnetite) is present. At Franklin, however, the ore-forming fluid was relatively poor in Fe^{+2} and the $Fe_2O_4^{-2}$ was neutralized in large part by Zn^{+2} and Mn^{+2}, and to a lesser extent by Fe^{+2} to give a mineral that is actually a solid solution of various amounts of magnetite, franklinite, and jacobsite, with $Mn_2O_4^{-2}$ substituted in small part for $Fe_2O_4^{-2}$ (7, p. 698).[3]

The spinel group is also represented at Franklin by gahnite, $ZnAl_2O_4$. The usual representative of the non-iron bearing members of the spinel groups in contact-metamorphic deposits is spinel proper, $MgAl_2O_4$, and its absence at Franklin is indicative of a low Mg^{+2} content in the ore fluid just as the presence of franklinite, instead of magnetite, is suggestive of a low Fe^{+2} content.

Olivines.—A low Fe^{+2} content of the ore fluid is also indicated by the silicates present. As Neuman (8, p. 578) has suggested, the 4-coordination and homopolar bonding of the zinc atom with oxygen prevents its complete substitution for Fe^{+2} or Mg^{+2} in the olivine lattice despite its similar ionic radius (0.79Å).[4] So instead of olivine, the phenacite-type mineral, willemite (Zn_2SiO_4), was formed at Franklin because the ore fluid was poor in Fe^{+2} and Mg^{+2} as well.[5]

[3] The absence of hausmannite, $MnMn_2O_4$, at Franklin is probably due to the low concentration of $Mn_2O_4^{-2}$ in the ore fluid which seems to have been sufficient only to allow $Mn_2O_4^{-2}$ to proxy for $Fe_2O_4^{-2}$ to a limited extent in franklinite but never was abundant enough to cause the formation of hausmannite as a distinct mineral.

[4] All ionic radii used in this paper are taken from Dana (7, pp. 4–5) with the exception of Cu^{+2} which is not given in Dana. Nockolds and Mitchell (9, p. 543) give Cu^{+2} as equal in radius to Fe^{+2} and it is so considered here despite the slight difference (0.04Å) between the Dana value and that given by Nockolds and Mitchell.

[5] The lack of appreciable Mg^{+2} in the Franklin ore fluid, as witnessed by its rarity in the gangue minerals (including the recrystallized calcite), also was an important control over the minerals formed and would make it likely that the ore fluid came from a silicic rather than a basic source magma, although this is not certain because the unusually complete oxidation of Fe^{+2} to Fe^{+3} (if it took place in the magma) would have increased greatly the need in the primary magma for 6-coordination Mg^{+2} to neutralize the various silicate anions. This point will be touched on further on pp. 187–188.

Tephroite (Mn_2SiO_4), on the other hand, actually is an olivine mineral in which Mn^{+2} easily proxies for Fe^{+2} or Mg^{+2}. If the zinc reported by chemical analysis in tephroite is really in the crystal lattice and is not present as sub-microscopic inclusions of zincite, it seems almost certain that the zinc is present as the unusual Zn^{+2} in 6-coordination.

Other rare olivines at Franklin include the uncommon minerals, calcium larsenite, $(Ca,Pb,Zn)_2SiO_4$, and larsenite, $PbZnSiO_4$, which are most strange in that they contain not only Zn^{+2} in 6-coordination, proxying for Fe^{+2} and Mg^{+2}, but also Pb^{+2} doing the same thing. The presence of lead in these minerals indicates that the ore fluid was not overly supplied with ions capable of proxying easily for Fe^{+2} and for Mg^{+2} in 6-coordination. Because its ionic radius in 6-coordination is 1.32Å (while that of Fe^{+2} is 0.79Å and Mg^{+2} 0.75Å) Pb^{+2} would not have been taken into these olivines were there sufficient cations (which were of the approximate size of Fe^{+2} and which would accept 6-coordination) available to neutralize completely the SiO_4^{-2} anions in the ore fluid. The probable presence of native lead in even slightly weathered calcium larsenite (1, p. 81) indicates that this mineral, while it can form at high temperatures, cannot retain lead in the more ordered lattice resulting from lowered temperature. The low lead content of the Franklin ores, then, probably is not due to a lack of lead in the ore fluid but to the great difficulty of getting lead ions into the contact silicate lattices. The presence of the small amount in the rare lead-bearing minerals rather indicates that the ore-forming medium at Franklin must have been high in lead to force even that much into the uncongenial silicate lattices. In addition, in the more common, though still rare, calcium larsenite, calcium substitutes for Fe^{+2} and Mg^{+2} without affecting the orthorhombic character of the mineral.[6] The incorporation of the considerably larger Ca^{+2} ion (ionic radius in 6-coordination = 1.01Å) in calcium larsenite definitely suggests a high solution content of Ca^{+2} (as is to be expected in solutions which have accomplished large scale replacements of limestone) and a low content of Fe^{+2} and Mg^{+2}.

Pyroxenes.—Among the pyroxenes at Franklin, instead of the normal diopside-hedenbergite of the typical contact deposit, schefferite, $Ca(Mg,Fe,Mn)Si_2O_6$, and jeffersonite (zincian schefferite), $Ca(Mg,Fe,Mn,Zn)Si_2O_6$, are present. Again the relatively low content of Fe^{+2} and the important amounts of Zn^{+2} and Mn^{+2} in the solutions are reflected in the mineral species developed. The lack of lead in these minerals is merely an expression of the practical impossibility, under natural conditions, of getting the large Pb^{+2} into the clinopyroxene lattice.

Instead of the usual wollastonite ($CaSiO_3$) of contact deposits, with relatively minor amounts of $MnSiO_3$ and $FeSiO_3$ in solid solution, the quite common variants at Franklin are bustamite, $CaMnSi_2O_6$, and fowlerite or zincian rhodonite, $(Mn,Ca,Zn,Fe)SiO_3$. Again these minerals are unusual in that they are essentially lacking in the Fe^{+2} which is to be found in natural wollastonite and rhodonite, $MnSiO_3$. The Zn^{+2} in fowlerite almost certainly

[6] Larnite (Ca_2SiO_4) is monoclinic and is also an exceedingly rare contact mineral, not known at Franklin.

must be in the 6-coordination and ionic bonding of the Ca^{+2}, Mn^{+2}, and Fe^{+2} for which it proxies. The lack of lead again does not demonstrate any paucity of it in the ore-forming fluid but rather the impossibility of forcing it into the triclinic lattice of the $CaSiO_3$-$MnSiO_3$ discontinuous series.

Melilites.—The melilite series is usually found in contact-metamorphic deposits as åkermanite, $Ca_2MgSi_2O_7$, which, as Neuman emphasizes (8, p. 578), contains Mg^{+2} in an unusual 4-coordination. It is not, therefore, surprising that hardystonite, $Ca_2ZnSi_2O_7$, is a relatively common mineral at Franklin because the normal coordination of zinc is 4. The lack of Fe^{+2} is explained because its coordination is normally 6 and it is only in slags that the iron-bearing melilite end member, $Ca_2FeSi_2O_7$, is important.

Epidotes.—The epidote group is common in contact zones and the member of the group found in exceeding rarity in the skarn at Franklin is hancockite, $Ca(Pb,Sr)(Al,Fe)_3(OH)Si_3O_{12}$. The replacement of Ca^{+2} by Pb^{+2} and Sr^{+2} in the epidote lattice demonstrates the abundance of lead in the ore fluid as lead under normal conditions substitutes for calcium in silicate lattices only in vanishingly small amounts. The substitution of strontium (ionic radius = 1.18Å in 6-coordination) for calcium in silicates is much more common than that of lead and is to be expected in the calcium-bearing silicate products of contact metamorphism. Allanite, containing radioactive uranium or thorium, as indicated by the rims of discoloration surrounding its crystals, and normal epidote, $Ca_2(Al,Fe,Mn)_3(OH)Si_3O_{12}$, are pegmatite minerals at Franklin.

Vesuvianite.—Vesuvianite in the copper-bearing variety, cyprine, is relatively abundant at Franklin and the beryllium-bearing variety has been found. The formulae for these Franklin varieties are uncertain and apparently add little to the knowledge of the composition of the ore-fluid except to indicate the presence of some copper. The essential lack of copper in any of the important Franklin minerals, however, would seem to indicate that the amount of copper in the ore-forming fluid was quite low. The ionic radius of $Cu^{+2} = \pm$ 0.79Å in 6-coordination makes it ideal to proxy for Fe^{+2} and probably for Mg^{+2} as well. Had Cu^{+2} been present in the Franklin ore fluid in comparable abundance to Zn^{+2} and Mn^{+2} it is likely that the deposit would be known for its unusual copper, rather than zinc and manganese, silicates and spinels. The reason for this apparent absence of copper in the ore fluid is considered in some detail on pages 189–190.

Garnets.—Garnet at Franklin is abundant and is of the variety andradite, $Ca_3(Fe,Al)_2(SiO_4)_3$, with a considerable amount of spessartite, $Mn_3(Fe,Al)_2(SiO_4)_3$, in solid solution in it. Important quantities of this garnet are found in pegmatite skarn zones and are undoubtedly due to the metamorphism of the limestone by solutions given off from the crystallizing pegmatitic lenses. But considerable volumes also are found in the ore at considerable distances from any pegmatite. The close association of garnet to both ore and pegmatite has been considered as evidence that the ore, as well as the garnet, was a product of contact metamorphism induced by the pegmatites. As Pinger and his associates have shown the ore to be later than the pegmatite, however, this concept is no longer tenable. Rather the essential identity

of garnets in pegmatite skarn and in ore skarn and in the areas where the two overlap must be charged to a similarity of source and composition (high Mn^{+2} and Fe^{+3} and low Fe^{+2}) of the ore fluids and the pegmatitic fusions. The lack of alamandite and pyrope is a tribute, again, to the low Fe^{+2} and Mg^{+2} content of the ore fluid and to the high concentration of Mn^{+2}. The presence of much more Fe^{+3} than Al^{+3} in the garnets is unusual and emphasizes the abundance of Fe^{+3} in the ore fluid.

Micas.—Manganophyllite, probably $K_2(Mn)_{6-x}(Mg,Fe)_x(OH)_4(Si,Al)_8O_{20}$, is the representative of the biotite group in the Franklin skarn and its composition indicates the low Fe^{+2} and Mg^{+2} concentrations of the ore fluid and the high Mn^{+2}. It is unique in being the only fairly common mineral at Franklin (outside the pegmatites) to contain potassium. This also brings out the lack of sodium-bearing minerals except for those in the pegmatites.

SUMMARY OF THE PYROMETASOMATIC CHARACTERISTICS OF THE FRANKLIN ORES.

From the preceding discussion, it is apparent that the typical gangue minerals of a contact-metamorphic deposit—garnet, spinel, diopside, wollastonite, epidote, biotite, olivine, and vesuvianite—are all present, in rather unusual chemical character it is true, in the Franklin skarn. It is also evident that the main ore mineral—franklinite—is only a variant of the spinel mineral, magnetite, that the other important ore mineral—willemite—is a phenacite-type mineral which, had Fe^{+2} or Mg^{+2} been available in quantity, probably would have been an olivine. The minor ore minerals—zincite and tephroite—are respectively a variant of periclase (MgO) and an unusual olivine, both not unlikely in a contact deposit.

Of the gangue minerals, the most common are the variants of garnet, wollastonite, diopside, and biotite—a normal contact-metamorphic assemblage. It seems probable then that the deposit at Franklin is a contact metamorphic one, not actually at an igneous contact, containing unusual ore and gangue varieties of common contact minerals because the ore solutions were abnormally low in Fe^{+2} and Mg^{+2} and probably in S^{-2} and Cu^{+2}, high in Mn^{+3} and well, though perhaps no more than normally, supplied with Zn^{+2} and probably with Pb^{+2}. Why such a set of conditions has obtained poses questions that I will attempt in part to answer in the following section of this paper.

THE FRANKLIN ORE-FORMING FLUID.

Iron in Igneous Magmas and Contact Deposits.—Wickman (10, pp. 380–381) points out that, as the average magma crystallizes, Fe^{+3} in the diminishing, still-fluid portion increases in relation to Fe^{+2}. He considers that this phenomenon can be explained as the result of two processes, each of which tends to concentrate Fe^{+3} over Fe^{+2} in the remaining liquid. The first of these is the greater acceptance of Fe^{+2} as compared with Fe^{+3} in dark silicates. The second is the simultaneous oxidation of Fe^{+2} to Fe^{+3}. In other words, Fe^{+2} is being removed from the melt at a faster rate than Fe^{+3} and at the same time a part of the Fe^{+2} still in the molten phase is being converted

to Fe^{+3}.[7] An examination of the average analyses of various igneous rocks, ranging from dunites to granites (11, p. 166), shows that an increase in the ratio Fe^{+3}/Fe^{+2} is to be noted from basic to acid rocks and probably reflects a similar enrichment of Fe^{+3} in the primordial earth magma to that which Wickman mentions for derivative magmas of later origin. Despite these variations in Fe^{+3}/Fe^{+2} ratio, no contact-metamorphic or *hydrothermal* iron deposits contain franklinite except Franklin-Sterling although several are related spatially, and probably genetically, to intermediate and even to acid rocks (Lyon Mountain). In short, in normal magmas under normal conditions of crystallization, there is always enough Fe^{+2} left in the late stages of the cycle to assure the presence in the ore fluid of enough Fe^{+2} to balance the $Fe_2O_4^{-2}$ anions it contains.

Franklin and Iron Springs.—Iron Springs, Utah (13, 14) is a rather peculiar contact-metamorphic deposit in which the large bulk of the iron is Fe^{+3} in hematite. This hematite, however, is not the original iron mineral in the important replacement ore bodies but is the result of the high temperature hydrothermal replacement of magnetite (13, p. 487) which last was deposited with its normal quota of Fe^{+2} ions. At Franklin, it must be remembered that the franklinite was deposited as such and is not the result of the replacement of magnetite. In other words, at Franklin the oxidation of Fe^{+2} took place before, and at Iron Springs after, magnetite deposition. Thus, though Franklin and Iron Springs are both unusual contact deposits, they are different and are probably due to different causes. This is indicated not only by the time of Fe^{+2} oxidation but also by the large Mn^{+2} content at Franklin as opposed to its essential lack at Iron Springs.

Having used Iron Springs to emphasize that the Franklin zinc ferrite is a primary ore mineral and not a replacement of a previously formed ferrous ferrite and that Mn^{+2} is lacking at Iron Springs and not abundant as at Franklin, it is necessary to concentrate on Franklin and leave the problem of the Iron Springs oxidation to some one else.

Iron, Manganese, and Magnesium at Franklin.—It seems that the low concentration of Fe^{+2} and the unusual abundance of Mn^{+2} in the Franklin ore fluid must have had a direct connection. This connection is not, of course, hard to discover for the half reactions:

$$Fe^{+2} = Fe^{+3} + e^{-1} = -0.77 \text{ volts}$$
$$Mn^{+2} = Mn^{+3} + e^{-1} = -1.51 \text{ volts}$$

indicate that the reaction

$$Fe^{+2} + Mn^{+3} = Mn^{+2} + Fe^{+3}$$

will go to the right, under standard conditions, with an emf of $+0.74$ volts (15, p. 526). This means that, either in the original magma or in the ore-forming fluid developed from it, there was enough Mn^{+3} to convert most of the Fe^{+2} available, i.e., not accepted into dark silicates, to Fe^{+3} while, at the same time, being itself converted to Mn^{+2}. This is confirmed by the lack

[7] The enrichment of Fe^{+3} relative to Mg^{+2}, which also is going on in the melt, is "somewhat obscured" by the oxidation of Fe^{+2} to Fe^{+3} but still is quite apparent (12, p. 229, et. seq.).

of really important amounts of Fe^{+2} or Mn^{+3} in the Franklin ore and gangue minerals.

In the normal ore deposits of hydrothermal origin it will be remembered that the manganese is in the manganous state while the much more abundant iron is in both ferric and ferrous states, indicating that there was not enough Mn^{+3} even when completely reduced to Mn^{+2} to oxidize more than a fraction of the Fe^{+2}.

If this oxidation of Fe^{+2} occurred largely in the main part of the cycle of magma crystallization rather than in the ore fluid, the amount of Mg^{+2} which would have been used up in the dark silicates would have been much more than in a magma in which Fe^{+2} oxidized to the customary much lesser degree. This excessive incorporation of Mg^{+2} in the dark silicates would have reduced the quantity available for the late-stage ore fluid considerably. That Mg^{+2} probably was present in the Franklin ore fluid only in small amount is indicated by the lack of dolomitization of the White Limestone and the rarity of magnesium-bearing ore and skarn minerals. Certainly, had Mg^{+2} been present in quantity, zincite, gahnite, and hardystonite would not have developed, instead periclase, spinel proper, and åkermanite, respectively, would have been formed.

The fact that the percent of Mn^{+2} in the Franklin ore is not equal to that of Fe^{+3} (as it should approximately be if the bulk of the oxidation of Fe^{+2} had been produced by the reduction of Mn^{+3}) suggests that, in the parent magma chamber, Mn^{+2} (ionic radius = 0.91Å) proxied for unavailable Fe^{+2} in the dark silicates and reduced by a considerable amount the Mn^{+2} which could go into the Franklin ore fluid. This further strengthens the possibility that the bulk of the oxidation of Fe^{+2} took place in the magma rather than in the ore-forming solutions.

Sulfur at Franklin.—The absence of sulfides in any appreciable quantity at Franklin is not particularly surprising as the amount of sulfide ore in typical magnetite contact deposits is not large. The amount of pyrite in the ore, however, certainly is less than in the average pyrometasomatic ore body, another indication of the scarcity of ferrous iron. The small quantities of sulfate minerals at Franklin indicate that there probably was no abnormally large oxidation of S^{-2} to the S^{+6} of SO_4^{-2}. This suggests that the generally later and lower temperature solutions which deposited the sulfides (sphalerite not unreasonably is the most common) did not contain any large quantities of Mn^{+3}. Had there been such, the S^{-2} would have been oxidized to, or close to, the limit set by the Mn^{+3} available. This is true because the oxidation potentials of the half reactions involved are such that the three steps of the reaction

$$S^{-2} + 8Mn^{+3} = S^{+6} + 8Mn^{+2}$$

all go easily to the right in acid or alkaline solutions (15, p. 526). This again suggests that the oxidation of Fe^{+2} to Fe^{+3} took place in the magma chamber and not in the upward moving ore fluid. This poses the problem of why all of the S^{-2} in the magma chamber was not oxidized to S^{+6} by Mn^{+3} because this reaction should proceed preferentially to the oxidation of Fe^{+2}

to Fe^{+3} by the same cation. The answer probably has been suggested by Weyl (16, p. 39) who points out that the zinc in silicate melts forms a tetrahedral structure with sulfur which is analogous to the silicon-oxygen tetrahedron. So long as the sulfur is locked up in this homopolar combination with zinc, the oxidation of S^{-2} by Mn^{+3} is inhibited and the sulfur remains in solution in the silicate magma until the development of the water-rich fluid provides a medium in which the zinc-sulfur complex anion is more soluble than in the silicate melt. This leaves the cations Fe^{+2} and Mn^{+3} free to react with each other approximately to the limit of their ability to do so.

Copper at Franklin.—Another problem posed by the Franklin deposit is the essential absence of copper which, as was mentioned previously, is unlikely had the ore-forming fluid carried copper in quantities of the same general order of magnitude as those of zinc. Had such an abundance of copper been present in the ore fluid it is difficult to see how the minerals formed would not have been copper-rich spinels, oxides, and silicates rather than those zinc-rich ones which actually occur. This follows because of the similarity in size, type, and field strength of Cu^{+2} (17, p. 221)[8] to Fe^{+2}. Had Cu^{+2} been available in quantity, it would have been much more likely to proxy for Fe^{+2} than Zn^{+2} which last has a greater preference for homopolar bonding and 4-coordination than Cu^{+2}. It might be put forward that copper was in the Franklin ore-fluid as Cu^{+1} which would not proxy for Fe^{+2} but against this it must be argued that Cu^{+1} would have oxidized to Cu^{+2} in the presence of Mn^{+3} in the parent magma chamber even more readily than Fe^{+2} to Fe^{+3} (15, p. 526). It is possible, of course, that the lack of copper in the ore fluid simply may reflect a lack of that element in the parent magma itself. The neighboring Paleozoic zinc deposits at Friedensville in Pennsylvania and the even closer zinc-lead ore bodies in the Shawangunk of southeastern New York also are lacking in copper and these occurrences may reflect an unusual deficiency in copper in the earth's crust of this general region. There is also the possibility, however, that copper was present in the magma and was prevented from concentrating in the ore-forming fluid for one or combination of both of two reasons. These are: (1) that the large bulk of the copper, oxidized to Cu^{+2} by Mn^{+3}, was accepted in the dark silicates crystallizing from the parent magma and essentially none was left over for incorporation in the ore fluid and (2) that much of the copper was incorporated in an immiscible sulfide melt developed early in the magma's cooling history. As to the first possibility, Nockolds and Mitchell (9) have shown that copper (as Cu^{+2}) is appreciably acceptable in the dark silicates which are basically iron-magnesium silicates. With a marked decrease in Fe^{+2}, due to the unusually large Mn^{+3} content in the Franklin-Sterling source magma, the opportunity for Cu^{+2} to enter the femic minerals would have been greatly increased and the copper left in the late stages of crystallization for incorporation in the water-rich ore fluid might well have been essentially nil. In connection with the second possibility, Rankama and Sahama (11,

[8] Neither Osborn nor his source (Dietzel) gives the field strength of copper but for Cu^{+2} in 6-coordination it is the same as for Fe^{+2} in 6-coordination. For Cu^{+2} in 4-coordination the field strength is the same as Zn^{+2} but Cu^{+2} has a greater tendency to form ionic bonds than does Zn^{+2}.

p. 969) point out that copper has a greater affinity for sulfur than iron or nickel. This indicates that in a basic magma rich enough in sulfur to cause the separation of an immiscible sulfide phase on cooling of the combined melt, the concentration of copper in the sulfide melt would greatly reduce the amount left in the molten silicates.[9] Obviously, both of these tendencies would operate in the same direction—the reduction or complete elimination of copper in the water-rich ore fluid when that phase developed.

The Non-Existence of Natural Copper Silicates and Spinels.—The lack of minerals at Franklin in which copper is the principal cation is, therefore, susceptible of explanation. It may be asked, however, why there are no copper-dominant silicates or spinels in other contact deposits in which the content of copper in the ore fluid must have been much higher than it is presumed to have been at Franklin. The answer to this probably is that, in the formation of such normal contact deposits, the ratio of Fe^{+2} to Cu^{+2} in the ore fluid was large and the Cu^{+2} concentration was continuously being reduced by its substitution (to a minor extent) for Fe^{+2} in the iron-rich contact minerals and never reached the value necessary to exceed the solubility products of any possible copper-dominant minerals. On the other hand, the minor development of such zinc-dominant minerals as willemite and tephroite, in certain high temperature deposits other than Franklin, can be explained by the difficulty of proxying Zn^{+2} for Fe^{+2} when the latter is abundant. This failure of Zn^{+2} to be subtracted from the ore-forming fluid, under normal conditions of contact metamorphism, locally may result in building up the Zn^{+2} concentration to the amount required to exceed the solubility product constant of one or more zinc silicates. Thus, it is possible that zinc-dominant silicates can form occasionally in a normal contact deposit but those of copper cannot. Only if an ore-forming fluid low in iron and rich in copper were to form a contact deposit could copper silicates, spinels, and simple oxides be developed and then only if the ore fluid were rich in the necessary anions and either poor in sulfide ions or above the temperature at which sulfides could precipitate. It is unlikely, moreover, that such an ore fluid often would be produced because, as has been suggested, the excessive oxidation of ferrous to ferric ion in the parent magma would force an unusually large proportion of the copper in that magma into the femic silicates and would, thereby, lower markedly the copper available for the ore fluid.

A Basic Source Magma for the Franklin Ore Fluid?—The inference is inescapable, that, if the copper content of the parent magma of the Franklin ores was reduced wholly or in part by the separation of a sulfide melt, the magma in question was a basic one. This follows from two lines of reasoning: (1) that ore bodies, such as Sudbury or Lancaster Gap, which formed at least in part from the solidification of sulfide melts, are closely associated spatially and genetically with basic rocks, and (2) that only basic rocks of

[9] It should be noted that Rankama and Sahama say that manganese has an even higher affinity for sulfur than copper but this has been determined mainly by slag studies and cannot apply to natural magmas and sulfide melts of magmatic origin in which alabandite is an uncommon mineral.

the primary outer shell of the earth could contain enough sulfides to form, on melting, a magma from which, on cooling, a sulfide melt would separate. So far as I know, the suggestion has never been put forward that the Franklin ore fluid derived from a basic magma and there are a good many arguments against it. For example, there are no basic rocks, except those much later in time, associated with the Franklin ores. In addition there is no extensive dolomitization or serpentinization of the host rock—Franklin Limestone—and of the silicate minerals developed in it as might have been expected had the source magma been basic. Of course, the paucity of Fe^{+2} in the parent magma would have reduced the amount of Mg^{+2} in the ore fluid considerably but, if that fluid had come from a basic magma, there still should have been much more Mg^{+2} in the Franklin minerals than there is. Finally, the pegmatites at Franklin, while pre-ore, are rich in manganese, if not in zinc, as is witnessed by the Mn^{+2}-rich garnet and manganiferous calcite contact skarns developed around them even at considerable distances from ore. This argues a common or similar parent for ore fluid and pegmatitic fusion. Although the variety of pegmatites at Franklin is wide (there are none at Sterling), they all are definitely of acid magma parentage and have produced by contact metamorphism many of the minerals so formed by the ore fluids.

Thus, as things stand now, it is unlikely that the Franklin ore fluid came from a basic magma. The probably low Fe^{+2} content of the magma seems to me to obviate the need for the removal of copper in a sulfide melt—it probably was all used up in neutralizing a fraction of the dark silicate anions crystallizing from the parent magma.

A Basic Source for Other Zinc-Lead Ore Fluids?—In a more normal deposit of zinc and lead, however, in which the copper content is low and the manganese content normal, I would suggest serious consideration be given to the possibility of the ore fluids in such cases having come from basic magmas from which the copper had been largely eliminated through the separation of an immiscible sulfide melt. The alternative to this mechanism is, of course, that the parent magma of the ore fluid in question was quite low in copper. The problem well may be resolved in those zinc-lead deposits low in copper, the time of emplacement of which can be established with a fair degree of certainty. In these, age determinations based on the ratio of lead isotopes (18, p. 1448) should give much older ages if the deposits were of basic rather than of intermediate or acid origin because of the much smaller content of radio-active elements in basic than in acid rocks. Presumably this is one of the possibilities Cannon had in mind when he wrote: "They (Nier's isotope determinations of ore leads) reaffirm the likelihood that lead ores originate from diverse sources."

CONCLUSIONS.

From the considerations presented in the course of this paper, it seems probable that the deposits at Franklin and Sterling are pyrometasomatic deposits whose unique mineral suite can be explained almost entirely as a consequence of an unusually high manganic ion content in the parent magma

of the ore fluid. Essentially all of the peculiarities of the deposit stem from this cause—the lack of lead is less directly related to this cause; lead is largely missing because it would not fit in the lattices of the minerals being formed. It only remains to explain the cause of the remarkable abundance of Mn^{+3} in the parent magma and anticlimatically I have no suggestion to offer but the heterogeneity of the primary earth. This is, of course, unsatisfying in the extreme but an attempt to explain the heterogeneity, were I competent to make it, would be far beyond the scope of this paper.

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GEOLOGICAL ACTIVITIES IN ASIA.[1]

CHINGYUAN Y. LI.[2]

Since the latter part of 1949, the writer has had the opportunity, as part of his work with the United Nations Economic Commission for Asia and the Far East, to visit Geological Surveys and related institutions in Burma, Ceylon, the Federation of Malaya, Hong Kong, India, Indonesia, Japan, Korea, Pakistan, the Philippines, and Thailand. It may be of interest to fellow-geologists in other parts of the world to know what kind of geological activities we have been carrying on in this region, especially so because as a result of political development, the region has emerged as one of the focal points in the world. International assistance has been coming through United Nations Technical Assistance Program, U. S. Point Four Program, and the British Commonwealth Council for Technical Cooperation in helping the development of mineral resources of this region.

The United Nations Economic Commission for Asia and the Far East, since its establishment in 1948, has been interested in helping the mineral resources development of the region. We began from a general survey of the mineral resources situation and came to make a comprehensive study of basic ones. Two reports on coal and iron ore resources have been circulated.[3] Considering the huge tonnage of lignites and laterites available in most countries of the region, we are currently investigating the best means for lignite utilization and measures for its improvement. The possibility of encouraging joint research and of inducing some country or countries of the region to set up a pilot plant is also being examined.

We were not satisfied with the general statement that the region as a whole has been inadequately surveyed, but have found out to what degree it has been so. From this finding, the Commission tried to find out the main bottlenecks, and came to investigate the possible sources of obtaining geologists,[4] facilities for their training,[4] and selective methods of geological survey.[4] It is not our belief that as the countries of the region move towards industrialization, mineral raw materials should be produced entirely for export, therefore we have started to investigate the possibility of establishing mineral industries in the region. Two reports have been made, one concerning the possibility of

[1] Published with the permission of Dr. P. S. Lokanathan, Executive Secretary of the United Nations Economic Commission for Asia and the Far East, and approval obtained from U. N. HQS in accordance with Staff Rule 8 of the Administrative Manual.

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[3] United Nations Economic Commission for Asia and the Far East documents E/CN.11/I&T/16 and E/CN.11/I&T/35.

[4] United Nations Economic Commission for Asia and the Far East document E/CN.11/I&T/36.

expanding aluminium industry,[5] the other related to mineral raw materials for fertilizer manufacture.[6] The third one, with regard to the sulphur resources of the region, is under preparation. We believe that the time has come to review the progress already made, to discuss the problems face to face with the experts of the region, and to seek their views on how to make rapid progress in the mineral resources development of the region. The Commission, therefore, has approved holding a meeting of experts on mineral resources drawn from the region and outside, including experts operating in the region under Technical Assistance or other programs, to exchange ideas, to review the progress already made, and to consider measures for the rapid development next year.

In addition, the writer, when circumstance permits, has rendered direct services to the governments of the region in investigating their particular resource problems on request. Such work has been done in Burma on the development of the Kalewa coalfield, in Ceylon on the iron ores, and recently in the Republic of Korea on the rehabilitation of coal and tungsten mines.

SYSTEMATIC SURVEY UNDERTAKEN TO-DATE.

The region as a whole is widely recognized as being inadequately explored, although it is not generally known to what degree this is so. In the countries visited, the writer has been impressed by the seriousness of the position.

India, Japan, and China, in comparison with other countries of the region, have a more advanced geological survey. However, even in India, excluding the portion of India which is covered by alluvium and barren lava flows (which do not at present require to be mapped in detail), the Geological Survey of India finds that approximately 28 percent of the country has been geologically surveyed on the one-inch scale, and that about 290,000 square miles remain to be surveyed on this scale. Assuming that, on the average, one geologist can survey 350 square miles in a field season, 830 man-years will be required before the one-inch geological map of India can be completed.

In China, the Geological Survey has recently published a geological map of China on a scale of 1 : 1,000,000. It has been estimated that, with the present strength of geologists, it would take at least fifteen years to complete a geological survey of the country on a scale of 1 : 200,000.

The geological sheet maps of Japan on a scale of 1 : 200,000 were completed in 1919. Prior to this, Dr. Kinosuke Inouye, Director of the Geological Survey of Japan, planned the work of 1 : 75,000 sheet maps. The Honshu, Shikoku and Kyushu regions were so mapped in 320 sheets. The sheet map survey was suspended at the end of 1942, but has resumed in 1946. Since 1950 it has been decided to cover the remaining unsurveyed areas on a scale of 1 : 50,000. 1,017 sheets of the new scale will have to be done in the next ten years.

[5] United Nations Economic Commission for Asia and the Far East document E/CN.11/I&T/29 Annex A.

[6] United Nations Economic Commission for Asia and the Far East document E/CN.11/I&T/33.

In Korea, no systematic geological mapping has ever taken place. The Japanese mapped, geologically, five percent of the country on a scale of 1 : 50,000, but these maps have not been considered reliable.

For other countries, Burma stands out well. As a result of the work of the former Geological Survey of India and oil companies about two-thirds of the country has been geologically surveyed either on the one-inch to a mile or one-quarter-of-an-inch scale. Unfortunately, data from Burma Oil Company is mostly not available.

In Ceylon, preliminary geological mapping on the scale of one inch to one mile was commenced early in 1940. Due to the war, and the lack of adequately trained staff, only a few sheets have been completed. So far the south-west section of the island has been fairly completely surveyed on this scale with the exception of small local areas : about one-third of the north-west sector has been mapped, but little work has been done in the north-east and south-east.

Up to 1941, a provisional geological map of the Federation of Malaya on a scale of one inch to 12 miles has been published, and reports and geological sketch maps, generally on a scale of one inch to four miles, existed for more developed areas such as South Perak, Selangor, Negri Sembilan and Malacca. Singapore Island had been geologically surveyed in detail. To date only about 3.5 percent of the area of the Federation of Malaya, i.e., 1765 square miles out of the total of 51,076 square miles has been surveyed on a scale of one mile to one inch and the maps published.

The British Colony of Hong Kong has been well surveyed. A geological map on a scale of 1 : 84,470 has been published, and detailed geological sheets on a scale of 1 : 20,000 are expected to be available soon. General geological maps of Indochina on a scale of 1 : 2,000,000 have been published. A more detailed map on a scale of 1 : 500,000 has been completed. Seven maps covering Hanoi, Cao Bang, Vinh, Hue, Tourane, Nhatrang and Saigon areas are on a scale of 1 : 100,000.

In Indonesia, the geological maps of Sumatra, Java, Western Borneo and New Guinea on a scale of 1 : 1,000,000 with still quite a number of blank spots, have been published. Eight percent of Java has been geologically mapped on a scale of 1 : 100,000 and the same percentage of Sumatra has been mapped on a scale of 1 : 200,000. The southwestern portion of Borneo has been mapped on a scale of 1 : 250,000.

In Pakistan, two-thirds of the country has been mapped on a scale of one-quarter-of-an-inch to one mile, mostly through reconnaissance works. Small portions are covered by one-inch-to-one-mile or two-inches-to-one-mile surveys.

In the Philippines, less than 10 percent of the country has been surveyed on a scale of 1 : 50,000 and in Korea only about 1 percent. The Geological Survey Department of the British Territories in Borneo was established only in 1949, and lack of accurate topographical maps hinders the start of a systematic geological survey.

In Thailand, there is a general reconnaissance map on a scale of 1 : 2,500,000 recently completed. No detailed systematic survey of the country has ever been attempted.

In view of the inadequate extent of surveys, the existing knowledge of mineral resources of the region is thus far complete.

PRESENT STRENGTH OF GOVERNMENT GEOLOGICAL SURVEYS AND SURVEY PROGRAM.

In order to carry out intensive and extensive geological survey work, considerable number of trained technical personnel will be required. With the exception of India and Japan, all government Geological Surveys of the region unfortunately are understaffed. The Geological Department of Burma has only one geologist; Ceylon and Indochina have two each; Thailand has four senior geologists. China has about seventy, but considering the size of the country, this number can hardly be called sufficient. The Philippines has 6 senior geologists and 7 geologists, not all of them, however, graduates in geology.

British Territories in Borneo.—The Geological Survey Department, British Territories in Borneo, was established in 1949, with headquarters at Kuching, Sarawak. Mr. D. W. Roe is the director. The survey operates over approximately 80,000 square miles, consisting of the Colonies of Sarawak (47,071 square miles) and North Borneo (approximately 31,000 square miles), and is in consultation with the British Resident, Brunei, which occupies 2,226 square miles and can be included.

The staff at present comprises, besides the director, one senior geologist and three geologists. Ten Asians have been recruited to date and are being trained as field assistants, draftsmen, and clerks. In addition, the temporary appointment of two United States geologists has been approved.

A start has been made with the mapping of districts where mineral deposits are known to occur; a geological reconnaissance of the extensive areas, concerning which little is known, will follow. Geological mapping on increasingly larger scale will be carried out as improved topographical maps become available. Work is proceeding on the topographical maps but is seriously hampered by lack of ground control for the preparation of maps from air photographs.

Burma.—In order to carry out mineral investigation work, the Government has planned to expand both the Geological and Mining Departments, which consist at present of one senior geologist and one mining advisor respectively. Dr. Ba Thi is the senior geologist in charge of the Geological Department with office at 226 Dalhousie Street, Rangoon.

Although no definite annual field program for systematic mapping has so far been proposed, for lack of geologists and unrest of the country, one of the major functions of the Burma Geological Department is to undertake the systematic mapping of the remaining one-third of the country which has not yet been mapped. However, priority will be given to areas which are known or suspected to be rich in minerals such as the Dawna Range in Amherst and Thaton districts, Naga Hills, Upper Chindwin, Katha, Myitkyina, and Yamethin districts.

The Government has taken concrete steps to explore the following mineral deposits: Kalewa and Theinday coalfields; Tavoy magnetite field. If the results prove satisfactory, plans for development of these deposits on modern lines under state ownership will be started.

Ceylon.—Ceylon does not have a geological survey or Bureau of Mines. The surveying work is entrusted to the Department of Mineralogy under the Ministry of Industries, Industrial Researches and Fisheries. Dr. L. J. D. Fernando is the Government Mineralogist in charge of the department, with office located at Colombo.

Preliminary geological mapping of the whole Island on a scale of one inch to one mile was initiated nearly ten years ago, but so far only a few sheets have been completed. In addition to completing them, it is hoped that these preliminary one-inch maps will form the basis for more detailed survey on the scale of one mile to six inches. In view of the limited technical staff, consisting of two qualified geologists, it may take some considerable time before this is achieved.

China.—The National Geological Survey of China has about 70 geologists and scientific officers. Dr. C. Y. Lee is the director, with the office in Nanking. It is understood that practically all the staff is engaged in field work in northern provinces, and a field station has been established in Mukden. This instiution has 10 laboratories: Geological mapping, Paleontology, Cenozoic Research, Mineralogy and Petrology, Economic Geology, Geophysical Laboratory, Soil, Chemical Laboratory for Analysis, Cartography and Engineering Geology.

Two branch offices are in Peking, for North East, and in Lanchow for North West.

Besides the National Geological Survey of China, there is a newly formed Academy of Science, under which there is a Research Institute of Geology which was formerly a part of Academica Sinica, now abolished. This institute has about 15 geologists.

Federation of Malaya.—The Geological Survey of the Federation of Malaya, which was established in 1903, consisted, until 1912, of a single geologist. The staff was increased until, during the period 1922–1931, four geologists were generally employed and good progress with the reconnaissance survey was made. After 1931 the staff was reduced to two geologists, but during the period 1938–1941, the establishment consisted of the director, mining geologist, five field geologists and two chemists. The survey at present consists of the same number of staff. Dr. C. T. Ingham is the director, with headquarters at Batu Garah, Ipoh, Malaya.

Up to 1941, a provisional geological map of Malaya on a scale of one inch to 12 miles had been published and reports and geological sketch maps, generally on a scale of one inch to four miles, existed for more developed areas such as South Perak, Selangor, Negri Sembilan, and Malacca. Singapore was the only other locality that had been geologically surveyed in detail. To date only about ten percent of the area of the Federation has been surveyed on a scale of one inch to one mile and maps published.

The preliminary object of the Federation of Malaya Geological Department during recent years was the detailed geological survey of Malaya on a scale of one inch to one mile. The detailed survey, while attempting to be progressively systematic, was designed to map firstly the more important mining areas and their possible extensions.

India.—The Geological Survey of India is already one century old. It has at present 150 geologists and other scientific officers. Many of the new recruits, however, require practical training before they can be entrusted with independent work. There are plans for expansion to a total of about 250 gazetted officers in the next few years. Dr. M. S. Krishnan is the Director of the Survey, with headquarters at 27 Chowringee Road, Calcutta.

The work of the survey is now organized on the basis of three main divisions. The first division consists of field circles, which are responsible for the detailed mapping of the country and for all preliminary investigations of mineral deposits or of water and engineering problems. The ultimate aim is to provide a field circle for every province.

The second division consists of the technical sections maintained at the headquarters in Calcutta, comprising the Chemical, Petrological, Paleontological, and Paleobotanical laboratories, the Geophysical Workshop, the Drawing office, the Mineral Information Bureau, the Statistical Section, and the sections responsible for general administration.

The third division consists of the specialist sections, which are available for work in any part of India. These sections are responsible for advanced studies in engineering geology and water supply, and for the detailed testing of mineral deposits by geophysical methods, drilling or exploratory mining.

These three divisions work in close collaboration. When the mineral deposits of an area have been generally appraised by the field circles and found promising, detailed testing by one or other of the specialist sections is carried out. The Survey endeavors not only to give advice to the public in carrying out their prospecting, development, and mining, but it is also extending its own investigations to the stage at which commercial possibilities become apparent.

During its 100 years of existence, the Geological Survey has accumulated a vast amount of information. It has a scientific library of over 80,000 volumes which is increased by nearly 5,000 volumes a year, obtained by purchase or by exchange.

Indochina.—The Geological Survey of Indochina, at present consisting of two geologists, is very short of personnel. The current situation precludes further field surveying work. Mr. E. Saurin is the chief of the survey.

Indonesia.—The Geological Survey Department at present has five geologists. Some of the experienced geologists have left. Mr. Sunu S. Susastro, Head of the Bureau of Mines, is also in charge of the Geological Survey. The Bureau of Mines is located in Djakarta, while the Survey is in Bandoeng.

Japan.—The Head-office of the Geological Survey of Japan is located at Hisamoto-cho, Kawasaki-city, not far from Tokyo, with branch-offices in Sapporo, Sendai, Osaka, and Kukuoka. Dr. Tomofusa Mitsuchi is the director

of the Survey which at present consists of more than 300 geologists and other scientific officers. There are five technical divisions in the Survey:

1. Geology: With sections on sheet mapping, stratigraphy and paleontology, petrology and mineralogy, and engineering geology.
2. Mineral deposits: With sections on metallics and non-metallics.
3. Fuel: With sections on coal and oil.
4. Geophysics: With sections on exploration and research.
5. Technology: With sections on topographic mapping and drawing, boring and chemical analysis, and machine shop.

Systematic geological surveying is being carried out on a scale of 1:50,000 as mentioned. One of the important contributions after the war was the prospecting of the deep coal-bearing strata under the sea by the seismic method. The existence of these strata has definitely been proved. By the investigation of Natural Resources Section, SCAP, a Petroleum Exploration Advancement Comittee has been formed to make geological and geophysical studies of the structurally prospective areas and also existing oil fields. For metallic ores, recent emphasis has been put on the investigation of zinc, copper, sulphur, and pyrite ores. For non-metallics, a survey has been made on mineral raw materials for ceramics and for fertilizer manufacture.

Pakistan.—At the time of partition, five Muslim assistant geologists from the Geological Survey of India applied for service in Pakistan and were appointed as geologists. The Geological Survey of Pakistan now consists of one director, one superintending geologist, eight geologists, seven assistant geologists, and three chemists. Dr. H. Crookshank is at present the director of the Survey located in Quetta, Pakistan. It is planned to have one more superintending geologist, thirteen more assistant geologists, one mining engineer, three driller and three geophysicists.

To enable the Survey to complete its work, it is necessary for it to be equipped with an up-to-date library and a laboratory. Efforts are being made to obtain duplicate copies of books from the library of the Geological Survey of India. It is hoped to establish at an early date a laboratory to analyze, test, and dress minerals.

Investigation into deposits of coal and limestone in East Bengal is being conducted by the Geological Survey of Pakistan. The Survey is also planning to map the ultrabasic rocks north of Karachi in Sind. It is also proposed to undertake a survey of the high Himalayan States of Chitral, Dir and Swat.

The Philippines.—The Geological Survey currently consists of 1 chief of division, 6 senior geologists, 7 geologists, 2 associate geologists, 12 assistant geologists, 3 junior geologists, 6 geologic aides, two junior topography-draftsmen, and one survey-draftsman. Not all geologists, however, were graduates in geology. Mr. Ramon Abarquez is the chief of the Survey which is under the Bureau of Mines located at Herran Street, Manila.

In 1950 seven parties were sent into the field to survey the following areas: Zamboanga and areas in the vicinity of Maria Cristina, Misamis Oriental and Occidental, Ilocos Region-Apayao District, Southern Surigao, Northern Surigao, Catanduanes, Coron, and Busuanga Island.

Thailand.—The Geological Survey Division of Thailand is at present under the Department of Mines. Mr. Vija Sreshthaputra is the chief in charge. It consists of four senior geologists, and about 10 assistant geologists. The temporary set of the organization comprises four sections: Geological Survey, Physics, Chemistry, and Museum.

A program is being laid out for carrying out detailed surveys of known lignite deposits in the peninsula and of gold deposits in the east. Exploration of crude petroleum is also under serious consideration. It requires a team of petroleum specialists, but these are not available from existing resources.

PRESENT FACILITIES FOR TRAINING GEOLOGISTS IN ASIA.

The previous section has shown that most of the countries do not have sufficient staff to carry out intensive and extensive geological surveys. This being the case, young graduates must be sought from the universities. The situation here is serious.

Most countries of the region do not have enough university facilities to train young men for the geological profession. Ceylon, the Federation of Malaya and Singapore, Hong Kong, Indochina, Korea, Nepal, and the British Territories in Borneo have no facilities at present. Geological studies were offered at the University of Hanoi in Indochina, but since 1945 they have been stopped due to the unsettled political situation. The University of Hong Kong is planning to have a department of geology within a few years. Burma has a department of geology in the University of Rangoon, but it is poorly equipped. The Technical University of Indonesia started a department of geology and mining in 1949. Courses in geology and mining engineering are being given in the Chulalongkorn University, Thailand. In the Philippines, geology courses are offered in the University of the Philippines, Adamson University, Mapua Institute of Technology, and FEATI Institute of Technology. As a result of World War II, none of the institutions in the Philippines has enough accommodations and all are short of library and laboratory facilities.

China, India, and Japan are the exceptions. Fourteen universities in India and the Indian School of Mines and Applied Geology offer training courses in geology, while China has five. There are twenty-three universities in Japan offering training in geology. Tokyo University has perhaps the best group of well-informed geologists in Japan, in addition to excellent departments in related sciences. The geology departments of Hokkaido, Kyoto, Kyushu, and Tohoku Universities are all considered to be outstanding in Japan.

INTERNATIONAL ASSISTANCE TO THE REGION IN THE FIELD OF GEOLOGY.

United Nations Technical Assistance.—The U.N. Technical Assistance program includes missions and expert advisory services, fellowships, scholarships, and distribution of technical information and seminars.

As of June 1, 1950, the following nominations for fellowships and recommendations for awards were made from the countries of the region:

Name of Member State Requesting Fellowships	Total Number of Candidates Nominated	Total Number of Recommendations for Awards
Burma	6	3
India	39	8
Pakistan	30	8
Philippines	11	3
Thailand	5	3

The principal fields of study in which candidates have been nominated for fellowships include economic geology, coal mining, and photogrammetry.

Assistance from United States.—Besides Japan, where geologists from SCAP and from the U. S. Geological Survey have been helping in many ways, India, Philippines, and Thailand have all had arrangements with the United States Government to obtain assistance from the U. S. Geological Survey. There are two geologists now stationed in the Philippines working closely with the Philippine Bureau of Mines. Under the Point Four Program, the United States Government sent three geologists to Thailand in 1949 to help solve problems concerning the exploitation of the nation's mineral resources. A coal expert (lignite expert) is attached in the ECA mission in Thailand to develop the lignite resources of the country. The Point Four Program recently concluded with India calls for three American geologists to work with the Geological Survey of India to develop mineral and ground water resources of India.

Assistance from the United Kingdom.—The Secretary of State of the United Kingdom for the Colonies has a team of expert advisers on geodetic, topographic, and geologic surveys. It is open to any colonial government to ask for expert technical advice from the Secretary of State on any problem relating to this field. There are also a number of Advisory Committees, which the Secretary of State may consult on any particular problem. Among these there is a Colonial Survey, Geophysical Survey, and Geophysical Committee. Special missions of experts are frequently appointed to undertake particular problems. Aerial photographic surveys have been carried out in Malaya, North Borneo and Sarawak, with the cooperation of the Royal Air Force. There are also a number of schemes for providing scholarships for colonial students at universities in the United Kingdom. The British Council also grants scholarships for students from countries outside the British Commonwealth.

CONCLUSIONS.

Realizing the key importance of mineral resources to the economic development of the region, nearly all Asiatic countries have programs to carry out additional geological surveys. It is clear from the above description that most of these countries suffer an acute shortage of technical personnel competent to carry out such surveys, and that university facilities whereby additional personnel could rapidly be trained are also lacking. With the assistance given by the United Nations and other countries outside the region, it can be hoped that the situation will be much improved in the near future.

UNITED NATIONS,
ECONOMIC COMMISSION FOR ASIA AND THE FAR EAST,
BANGKOK, THAILAND,
August 3, 1951.

A STUDY OF THE SEYLER THEORY OF COAL REFLECTANCE.[1]

J. T. McCARTNEY.

ABSTRACT.

Investigations of the optical properties of the petrographic constituents of coal are reviewed, and a summary is given of the Seyler theory that the components of coal derived from woody tissue, such as anthraxylon and fusain, have reflectances that can be arranged in a discontinuous series. A description is given of the apparatus used to test this theory. The application of accepted reflectance theories to results obtained with this equipment on standard minerals is described, and the accuracy and duplicability of determinations on these minerals and on coal are calculated.

Graphical results are given of two procedures for testing the Seyler theory. The results are discussed, and a general appraisal of the theory is presented. It is concluded that Seyler's theory is not substantiated by this study, but that his descriptions of reflectance variations in the constituents of coal may be of considerable value in petrographic analysis.

INTRODUCTION.

QUANTITATIVE measurements of light reflected from the petrographic constituents of coal were first reported by Hoffman and Jenkner (1) [2] in 1932. They used a slit microphotometer designed by Berek (2). Their observations were confined to anthraxylon or vitrain bands, and they reported that the percentage of vertically incident light reflected in air increased with the rank of the coal. McCabe and Quirke (3) made later studies of variations in the optical properties of coal with rank, but they measured the angle of polarization of obliquely reflected light and the related indexes of refraction of anthraxylon bands. They also found an increase in index of refraction with rank. Cannon and George (4) made further studies and reached similar general conclusions, although there were some exceptions to the general increase of index of refraction with rank, particularly with the highest-rank coals, where a decrease in index occurred. These latter observations were complicated by the appearance of anisotropy in the higher-rank coals, which affected the values depending on the orientation of the samples. In none of these studies was any quantitative relationship of rank to reflectance or index of refraction expressed.

Seyler (5, 6, 7, 8) has applied quantitative measurements of coal reflectances in a more general way with rather startling results. He also used the Berek microphotometer, but introduced cedar oil as his observational medium and did not restrict his determinations to megascopic anthraxylon bands. His studies resulted in an interesting theory that has attracted con-

[1] Presented at the meeting of the Society of Economic Geologists, Coal Geology Section, Detroit, November, 1951.

[2] Numbers in parentheses refer to bibliography at end of paper.

siderable attention. Seyler stated that the constituents of coal derived from wood or bark, excluding spores, cuticles, and resins, have reflectances that vary discontinuously and can be arranged in a fixed series of nine steps that are related to each other by a geometrical progression. The reflectance in oil could be represented by the equation $R = 0.26 \times 1.363^{N_R}$, where N_R is the number of the component, from 1 to 9. The predominant and usually the lowest ulmic component present in bright coals was called vitrinite, and the highest component, No. 9, was named fusinite. The intervening components were classed as intermediates. Generally, only three or four of these components were present in appreciable quantities in any one coal. Seyler also postulated that, as the coal increased in rank through metamorphism, the components present suddenly mutated to the next higher step. As an example, there might be in a low-rank subbituminous coal a preponderance of component 3, which would be the vitrinite, with smaller amounts of higher components. In higher-rank coals, the vitrinite might be components 4, 5, 6, and so on, until ultimately a coal that had reached the limit of metamorphic alteration would consist entirely of component 9, called either vitrinite or fusinite, which in this case would be synonymous.

This theory should be amenable to verification in two ways. If the reflectances of anthraxylon or vitrain bands in a series of coals of varying rank were measured, the values should coincide with different steps in Seyler's series. Also, if a number of reflectance determinations were made on the woody constituents of any one coal, these should also fall in several discontinuous groups.

The object of this paper is to present the results obtained in such attempts to test the validity of Seyler's proposals.

EXPERIMENTAL PROCEDURE.

The apparatus used was assembled to duplicate that described by Seyler. A diagram of the Berek microphotometer is shown in Figure 1. The incident light is divided into two beams by the partly reflecting prism A. One part passes through a polarizing prism B, an iris diaphragm C, a collimating lens D, and then is reflected downward to the specimen E by the prism of the vertical illuminator. The light reflected from the specimen passes up through the microscope tube to the photometric cube. The other part of the incident light passes through one of a series of filters of varying transparence at F, then is reflected by an adjustable prism G to polarizing and analyzing prisms at I and H. The amount of light passing through is dependent on the relative settings of the two prisms, the angular position of the analyzer being read on the scale J. An eyepiece, K, can be focused on this scale. The emergent light strikes the photometer cube L, illuminating half of the circular field, the other half being illuminated by the light reflected from the specimen. A Ramsden eyepiece, N, is used to observe the divided field. In making observations, the two halves of the field are matched by varying the setting of the analyzer.

The microphotometer is mounted on a Leitz Panphot microscope. The regular filament lamp (6 v 5 a) of this assembly was used for some of the measurements described in this study, but, because of the very low reflectance of the lowest-rank coal constituents, many of the observations were made with a 500-watt projection-type lamp with a variable transformer. All of the determinations were made, however, at as low intensities as could be used efficiently, as accuracy has been reported better at low-intensity levels. A green filter, as recommended by Seyler, and a ground glass were used to

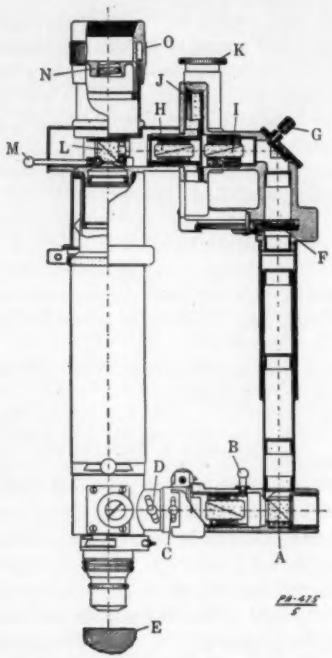

FIG. 1. Leitz Slit Microphotometer. (Courtesy of E. Leitz, Inc.)

condition the illumination. The adjustable slit furnished with the microphotometer was reduced to a small opening, and the iris diaphragm of the vertical illuminator was closed as far as possible. This restricted the light incident on the specimen to a very narrow beam and reduced the observed area to a size only slightly larger than the field of the photometer cube. A 1/12-inch oil-immersion lens was used with cedar oil of refractive index 1.511 for all reflectance observations on coal.

THEORY OF REFLECTANCE AND CALIBRATION OF THE MICROPHOTOMETER.

According to a theoretical analysis of reflection first developed by Fresnel, the reflecting power of a transparent dielectric can be represented by the equation $r = \frac{(n-1)^2}{(n+1)^2}$, where n is the index of refraction. When the absorption of light by the material must be considered, the relation becomes $r = \frac{(n-1)^2 + n^2K^2}{(n+1)^2 + n^2K^2}$, K being the absorption index. Cannon and George (4) found that the absorption index of low-rank coals is small for light of long wave length, but that it increases with rank of the coal and decreasing wave length of light. However, they also found that the approximate values of index of refraction obtained from the angle of polarization, or Brewster angle, were not more than 5 percent in error and less than this for low-rank coals.

In order to calibrate the Berek microphotometer and also to compare the results obtained with those derived from reflectance theory, observations were made on several transparent minerals. A monochromatic sodium source was used for these measurements. A quartz plate of known reflectance, furnished with the microphotometer, was used as a standard. Two synthetic minerals, spinel, $MgO \cdot Al_2O_3$, and calcium tungstate, $CaWO_4$, and a natural specimen of sphalerite, ZnS, were observed. Their reflectances were calculated from the formula $r = \frac{(n-1)^2}{(n+1)^2}$, using indexes of refraction taken from the literature. Using a 14 mm dry lens, readings were made with the microphotometer, and the reflectances of the minerals were calculated by the formula $r_m = \frac{r_q \sin^2 \theta_m}{\sin^2 \theta_q}$, where θ_m and θ_q were the angular settings of the analyzer for the mineral and quartz, respectively. The results are shown in Table 1. Three series of observations were made on each mineral. The agreement between the averages of these and the calculated reflectances is excellent.

TABLE 1.

COMPARISON OF THEORETICAL AND OBSERVED VALUES OF REFLECTANCE OF MINERALS IN AIR AND IN CEDAR OIL, USING SODIUM LIGHT

Specimen	Reflectance in air, percent					Reflectance in oil, percent	
	Calculated	Observed				Calculated	Observed
		1	2	3	Ave.		
Quartz, SiO_2	4.6	—	—	—	—	0.01	—
Spinel, $MgO \cdot Al_2O_3$	7.0	6.7	7.0	6.9	6.9	0.43	0.41
Calcium tungstate, $CaWO_4$	10.0	10.3	10.2	9.8	10.1	1.46	1.41
Sphalerite, ZnS	16.5	16.8	16.3	16.5	16.5	4.88	—

Determinations also were made on the three minerals with the 1/7-inch oil immersion lens. The reflectances in cedar oil were calculated from the formula $r = \frac{(n - n_0)^2}{(n + n_0)^2}$, n_0 being the index of refraction of the oil, again using literature values of n. As quartz has too low a reflectance under oil to be measurable, the sphalerite was taken as a standard, and the reflectances of the other two minerals were calculated from the microphotometer readings. These results also are shown in Table 1. Again, excellent agreement was obtained. These studies indicate that the desired reflectance property can be measured accurately by the Berek microphotometer.

For the routine calibration of observations on coal, the quartz was used as a primary standard, and the reflectance of sphalerite (used as a secondary standard) was calculated from readings in air with the green illumination. From these, an observed index of refraction of sphalerite in green light was calculated from $r = \frac{(n - 1)^2}{(n + 1)^2}$. This was substituted in the equation $r = \frac{(n - n_0)^2}{(n + n_0)^2}$, and the reflectance of sphalerite in oil (green light) was calculated. The readings on coal with the microphotometer could then be converted to percent reflectance by comparison with the readings of sphalerite in oil. Periodic checks of the latter served to show whether any change in instrumental conditions had occurred.

ACCURACY OF DETERMINATIONS.

To ascertain the accuracy and reproducibility of the observations, another observer joined with the author in a series of determinations. All settings of the microphotometer were made by one observer and read by the other. A variation of the standard deviation developed by Prof. Karl Pearson, known as the coefficient of variation, will be used to compare the results on minerals and coal. The coefficient of variation of a set of determinations is the ratio of the standard deviation to the average, expressed as a percentage.

The coefficient of variation of each determination in a series on sphalerite in oil was found to be 2.3 percent for the author and 4.1 percent for the less experienced observer. These compare with a reported 2.4 percent obtained in Seyler's laboratory. The coefficients of variation for single observations on anthraxylon bands in three coals averaged 3.8 percent for the author and 6.7 percent for the other observer. The coefficients of variation for the averages of a set of readings, such as are always made on each spot, would, of course, be much less. For most of the authors results, in which six readings were made on each spot, the calculated coefficient of variation for coal would be $\frac{3.8}{\sqrt{6}} = 1.6$ percent. This accuracy is more than sufficient to detect the stepwise variations described by Seyler. The observed coefficient of variation for anthraxylon bands in 10 coals was 5.9 percent. Comparison of these two figures indicates the variations in reflectance of supposedly uniform bands.

RESULTS.

Reflectance determinations were made on anthraxylon or vitrain bands in 16 coals of varying rank. Samples of about half of these were reasonably fresh, whereas the remainder were old samples available in the laboratory. Seven or eight different spots were observed in each sample, and six readings were made on each. The averages for each sample are plotted in Figure 2. The rank of the coals is based on the American Society for Testing Materials classification standards (9). It can be seen that there is little or no agreement with the steps of Seyler's series. There is a general increase of reflectance with rank, as found by previous investigators, but there are several exceptions, the most noticeable being one of the Pocahontas No. 3 samples.

	Mineral-matter-free analysis				
	Coal bed	State	Fixed carbon, dry, percent	B. t. u., moist	Rank
a	Lenox	Colorado	57.6	12,400	Sub bit. A
b	Illinois No. 6	Illinois	55.4	12,530	High-vol. C bit.
c	Illinois No. 6	Illinois	61.2	13,210	High-vol. B bit.
d	Henryetta	Oklahoma	62.0	13,800	High-vol. B bit.
e	Lower Sunnyside	Utah	58.6	13,960	High-vol. B bit.
f	Illinois No. 5	Illinois	61.1	14,810	High-vol. A bit.
g	Pittsburgh	Pennsylvania	59.9	14,860	High-vol. A bit.
h	Pittsburgh	West Virginia	55.6	15,030	High-vol. A bit.
i	Eagle	West Virginia	66.1	15,200	High-vol. A bit.
j	Lower Kittanning	Pennsylvania	77.0		Med.-vol. bit.
k	Beckley	West Virginia	79.5		Low-vol. bit.
l	Pocahontas No.4	West Virginia	81.8		Low-vol. bit.
m	Pocahontas No.3	West Virginia	82.0		Low-vol. bit.
n	Pocahontas No.3	West Virginia	83.9		Low-vol. bit.
o	Bernice	Pennsylvania	90.4		Semi-anthracite
p	Lower Baltimore	Pennsylvania	94.2		Anthracite

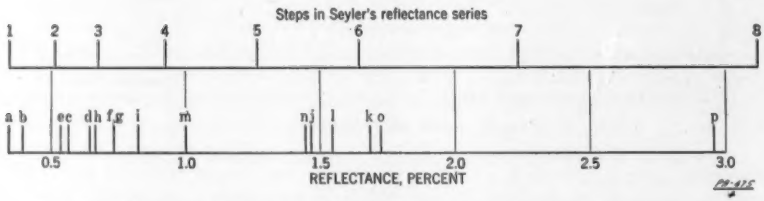

FIG. 2. Average reflectances of anthraxylon bands in coals of different rank.

A study of the reflectances of the different areas in a band indicates that adherence to an orderly stepwise progression could hardly be expected. The ranges of values from the areas of lowest to highest reflectance in any one band averaged about 50 percent of the difference between the nearest two Seyler steps, whereas the standard deviation of the determinations would indicate that, if the bands were of strictly uniform reflectance, 95 percent of the values should not vary more than 20 percent of the difference between steps. Apparently, then, there are definite variations in reflectance over the

supposedly uniform anthraxylon bands, not enough to be caused by the presence of two components of the series but large enough to be an appreciable fraction of the difference between two successive steps. In one of the samples, in particular, there was a marked difference between two adjacent anthraxylon bands. The average reflectance of eight spots in one of these was 0.68 percent and of six spots in the other 0.81 percent. The difference is 52 percent of the range between the nearest two steps.

To investigate components of different reflectance in the same coal, eight series of determinations were made on sample blocks of attritus from six different coals. In seven of these sets, six observations were made on each of 35 to 40 different minute areas of uniform reflectance. These were made

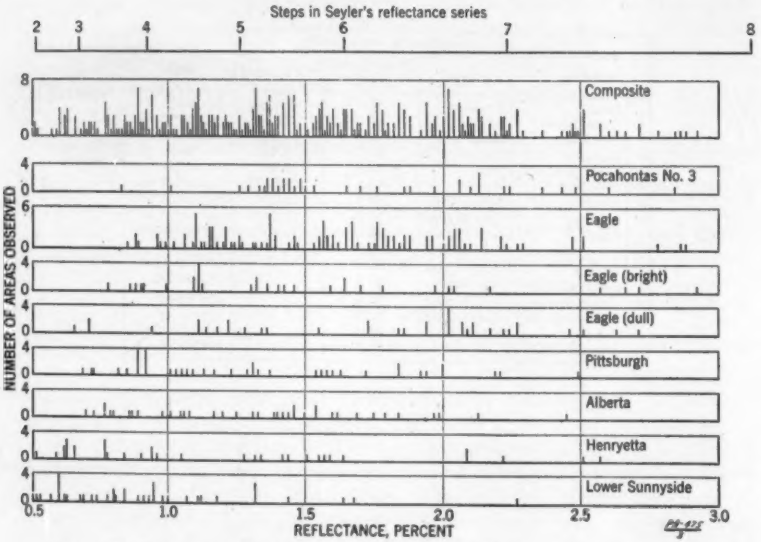

FIG. 3. Frequency of occurrence of various reflectance values in coal.

at random on areas that were large enough to fill the photometer field and as uniform and free from scratches as possible. In the eighth set, 123 areas in one coal were examined. These data are shown in Figure 3. All readings also are shown combined in one composite graph. According to the Seyler theory, there should be discontinuous grouping of the reflectance values at or near the steps in the series. There does not appear to be any such ordered arrangement.

EFFECT OF POLISHING ON REFLECTANCE.

One of the main variables that might affect the accuracy and reproducibility of reflectance determinations is the method and quality of polishing. To in-

vestigate this factor, studies were made on anthraxylon bands in two coals of quite different rank. These were first polished with cerium oxide on soft cloth, and the reflectance was determined at a number of spots in the band. The polish was then completely removed, and the same procedure was repeated. After again removing the polish, the specimens were polished with green chromium oxide on a leather strop, and the reflectance was determined as before. This procedure, also, was repeated once. The following average reflectance values were obtained: For Pittsburgh bed high-volatile anthraxylon, 0.56 and 0.57 percent reflectance on successive polishings with cerium oxide on cloth and 0.56 and 0.60 percent for successive polishings with chromium oxide on leather; for Pocahontas No. 3 low-volatile anthraxylon, 1.46 and 1.52 percent reflectance with cerium oxide polishings and 1.42 and 1.45 percent with chromium oxide. It is apparent that the agreement of these results is good, certainly being no worse than the variations found previously in similar bands. Thus, it may be concluded that the method or quality of polishing does not appreciably affect the results.

DISCUSSION OF RESULTS.

Coal is a heterogeneous and complex organic material composed of many constituents. Even though the Seyler theory is concerned only with the ligno-cellulosic components, these still consist of complex and unknown chemical combinations. Chemical analyses of uniform and apparently structureless anthraxylon bands have shown no discontinuous variation in any element with change in rank. It would therefore be quite surprising if there could be shown to be any regular discontinuous change in a physical property such as reflectance or the index of refraction on which it depends. It is evident from the results presented that the Seyler theory of discontinuous steps is not substantiated by this study of a limited number of American coals.

Ignoring the quantitative data and the conclusions drawn therefrom, the following are some subjective and qualitative observations of the appearance of the various microconstituents of coal with an oil-immersion lens. The differences in reflectance of the many microscopical bits of woody tissue in an attrital band are definite and striking to the eye. Most of them are apparently of uniform brightness, but in some cases there is an observable gradual variation from one part to another. In many instances there are sharply defined adjacent areas, the reflectances of which vary by a very small amount, which upon measurement proves to be considerably less than the differences between steps in the series. Thus, there are exceptions to the theory evident to the eye with little or no measuring necessary.

The inability of various investigators to agree on the reflectances of minerals of known chemical composition demonstrates the difficulty of proving the existence of a series of unvarying and universal reflectance values in a material as complex as coal. Short (10) summarizes investigations of reflectance of minerals by several workers, including studies with the Berek microphotometer and with photoelectric cells. These investigators differ as to the effect of quality of polish and deviations from exact normality of the incident light on

the reflectance obtained. Certainly, their results on a supposedly uniform mineral such as sphalerite differ by an appreciable amount. Values of 15.5 to 16.0 percent (depending on color of light) are quoted for one worker who used the Berek microphotometer and 18 percent for another. Values of 17.9 and 18.5 percent are given for photoelectric-cell determinations. When such differences are found for a relatively pure mineral, the difficulties of detecting exact reflectance steps separated by fractions of a percent in a complex substance like coal can be appreciated easily.

Regardless of the failure of this investigation to substantiate the reflectance theory of Seyler, it is felt that his description of the variations in reflectance of the constituents of coal derived from woody tissue is a significant and valuable contribution to the petrography of coal. They offer an objective basis for classifying the petrographical constituents that may become an important complement to the subjective qualitative descriptions that have been presented heretofore. It may be possible to establish arbitrary classes or limits of reflectance and use these as a basis for quantitative analysis of either columnar or crushed coal samples that could be of considerable value in defining the petrographic constituents of coal present.

ACKNOWLEDGMENT.

The author wishes to express his appreciation to W. A. Selvig, supervising chemist, Coal Constitution and Miscellaneous Analysis Section, Central Experiment Station, Bureau of Mines, Pittsburgh, Pa., under whose general supervision this investigation was conducted.

COAL CONSTITUTION AND MISCELLANEOUS ANALYSIS SECTION,
U. S. BUREAU OF MINES,
PITTSBURGH 13, PA.,
Oct. 14, 1951.

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DISCUSSIONS

"A STUDY OF THE SEYLER THEORY OF COAL REFLECTANCE."

Sir: In the first place I must criticize the title of this paper [1] and the continued reference to the Seyler "theory" of coal reflectance. The word "theory" is used no less than five times in the abstract of McCartney's paper. There is no Seyler "theory" of reflectance. I always try to avoid premature theory about any subject and have even devised an aphorism on the lines of Occam's razor which has become known in certain circles as "Seyler's bludgeon," viz., *Prius res quam rationes,* which may be roughly translated into English as "Don't be in a hurry to explain every single thing."

The difference between us is one of observation or *fact,* not at all of a *theory.* My thesis is that coal is a rock composed of one or more homogeneous "components" which, when derived from woody tissues, increase in oil reflectance, either by metamorphism, whether natural or artificial (carbonisation) or by diagenesis. These changes do not form a continuous series, but take place by a small number of steps, ten in number from lignite to anthracite or to fusinite. The reflectance of all these steps has been measured, except No. 9 of anthracite. These steps moreover form a geometric series with a common ratio of about 1.36 and can be represented by the formula

$$R_0 = 0.26 \times 1.36^{N_R},$$

where R_0 is the reflectance in oil, 0.26 the reflectance of the lowest component of lignite yet found and N_R is a whole number from 0 to 9. Step No. 9 is the highest reflectance that has yet been found in any coal and was termed by me at the 2nd International Stratigraphical Conference at Heerlen in 1935 *fusinite.* Consequently the reflectance of the vitrinite in oil cannot be used as a measure of the rank of an individual coal, but only to classify coals into ten species of increasing rank, numbered 0 to 9. The vitrinite of each of these species has a constant reflectance and a particular range of elementary composition and volatile matter between limits which are characteristic for each species. This consequence must be very unwelcome to those chemists who have devised systems of classification based upon the elementary composition or volatile matter of *average* samples of coal. The exact rank can only be measured in terms of the properties of the vitrinite. It appears likely that the limit of composition and volatile matter of these species will be the same in all coals, but I cannot be certain of this until more experiments have been made. I prefer the C and H, or the ratio of C/H, to the V.M. as the meas-

[1] McCartney, J. T., A study of the Seyler theory of coal reflectance: Econ. Geol., vol. 47, no. 2, pp. 202–210, 1952.

ure of the change of rank. As, however, the C is increased by diagenetic processes, i.e., by the change to fusinite, it is evident that the C of an average sample containing appreciable amounts of fusinite or intermediates between fusinite and vitrinite must affect the judgment of rank based on the average C. Rank must no longer be judged by the elementary analysis or V.M. of an average sample unless it should happen to consist entirely or mainly of vitrinite, or a correction can be made from the petrological analysis.

Figure 1 gives a graph of the components of coal of carbon below graphite, both by metamorphic and diagenetic changes. Each "component" is dis-

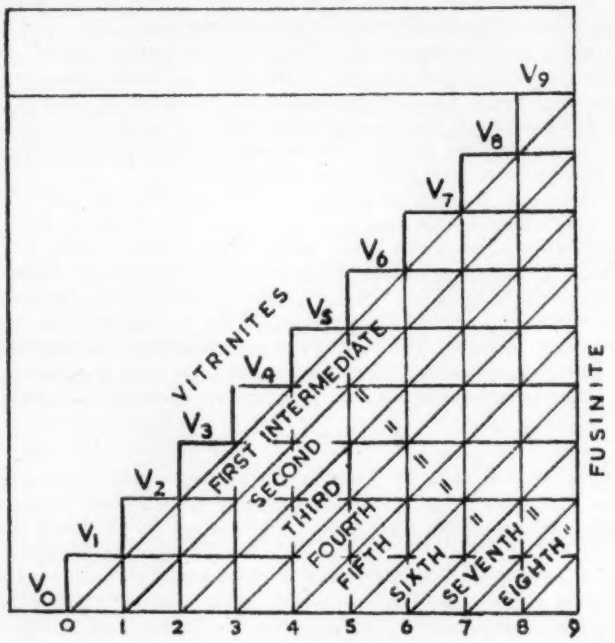

FIG. 1. The process of metamorphism and fusinisation; petrological spectra of coal.

tinguished by its reflectance number (N_R) alone. The main component, called vitrinite, is almost invariably the lowest reflectance of the woody ones. The reflectance of the fusinite is that of No. 9, viz., 4.17 and remains constant through all changes of rank.

McCartney disputes the fundamental observation that the change of reflectance is stepwise, both in metamorphosis and diagenesis. Still more, of course, is the mathematical relation between the components in dispute by his failure to verify my results.

In view of the fact that no one had troubled to verify my results since they were published in the Melchett Lecture in 1943 and that these observations were made mainly by one assistant in my laboratories, I felt hopeful that McCartney would be able to confirm them. Because of his inability to do so I took advantage of the fact that an Indian geologist, Mr. B. C. Mukherjee, had asked to work on the reflectance of coal in the petrological laboratory of B.C.U.R.A. The following table gives a specimen of his results:

Origin of coal	R_0	Seyler's standard	Component no.	Ratio
Alberta, Canada	0.54	0.51	2	
				1.214
South Africa	0.66	0.67	3	
				1.371
U. K.	0.90	0.92	4	
				1.388
Germany	1.25	1.26	5	
				1.324
Victoria	1.65	1.64	6	
				1.367
Germany	2.26	2.23	7	
				1.397
Fusain (U. S. A.)	3.16	3.11	8	
				1.319
Fusain (U. S. A.)	4.17	4.17	9	

Mr. Mukherjee also showed that the reflection in air followed a stepwise course, but with a much smaller ratio between adjacent components (1.08 to 1.27).

Following this I had a number of observers who spent a couple of months in studying the new technique. Dr. Stach sent me four University students who each made about 100 measurements (each the mean of 10 observations). They fully corroborated the fact of the stepwise change of coal both by metamorphosis and diagenesis. Their mean results may be summarized as follows:

	No. 0	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9
Students' results	0.26	0.33	0.51	0.67	0.92	1.25	1.64	2.20	3.13	4.22
Seyler's standards	0.26	0.34	0.51	0.67	0.92	1.26	1.64	2.23	3.11	4.17

The results were taken at random from the components of the samples, not only the vitrinite but all the steps between this and fusinite. No component of greater reflectance than No. 9 (mean R_0 4.22%) was found in coals from any country. The full results are contained in B.C.U.R.A. Information Circulars Nos. 46 and 48, and will be published shortly in "Fuel".

In addition, Dr. D. W. van Krevelen, Director of Research of the Central Laboratory of the Dutch State Mines, sent his assistant, Mr. F. J. Huntjens, to the petrological laboratory at B.C.U.R.A. He learned the technique and confirmed our figures in all components from 2 to 8. Dr. van Krevelen wrote saying that both he and Mr. Huntjens were now convinced that my conceptions (of the stepwise changes in the reflectance of coal) were absolutely "safe."

Although the results shown by McCartney in Figure 3 obtained from pure anthraxylon (i.e., under the most favorable conditions for good polish) do

not show a random distribution, it is impossible to deduce from them a satisfactory agreement with Seyler's reflectance steps. The reflectances obtained from individual samples of coal shown in his Figure 4 certainly give a random distribution especially when compounded. I have been unable to account for this disorder which is so markedly different from the order obtained by some dozen workers in B.C.U.R.A. laboratory.

I have examined three samples of American coals sent me by Dr. Fieldner, two of which are included in McCartney's paper as samples, viz., Lower Kittanning (J) and Beckley Bed (K). The petrological analysis (by volume) is as follows:

Description of sample	Component	Reflectance R_0	Seyler's component no.	Percent present	Parr's	
					C	H
Beckley Bed (parent coal)	Vitrinite	1.64%	6	86.8	90.86	4.56
Winding Gulf Colliery, Winding Gulf No. 1	1st Intermediate	2.26	7	6.9		
	2nd Intermediate	3.1	8	3.5		
	3rd Intermediate	4.11	9	2.8		
Lower Kittanning (parent coal) Indian Creek Coal & Coke Co.	Vitrinite	1.25	5	85.5		
	1st Intermediate	1.64	6	2.1	88.65	5.13
	2nd Intermediate	2.28	7	8.1		
	3rd Intermediate	3.1	8	4.3		

The Lower Kittanning (J) taken from McCartney's graph has a reflectance of 1.47 whereas I found 1.25, difference = 0.22%. This result is very bad. The Beckley Bed (K) in McCartney's graph has a reflectance of 1.69 against my figure of 1.64, difference = 0.05%. This result is quite good.

I am convinced from other experiments I have made on American coals and fusains, and many experiments with Canadian coals, that the reflectance of the American coals in dispute does not differ from those we have found from all over the world.

In conclusion, it seems to me that the quickest way to settle these differences is to send Mr. McCartney or some reliable American to make a joint examination of the coals in dispute in B.C.U.R.A. laboratories. I have already, a long time ago, asked Dr. Fieldner if he could do so but no opportunity has yet occurred.

CLARENCE A. SEYLER.

B.C.U.R.A.,
RANDALLS RD.,
LEATHERHEAD, SURREY,
Nov. 16, 1951.

A REPLY.

Sir: Dr. Seyler presents in his discussion the results obtained in his laboratory by a number of foreign observers who visited him to study his technique. It would have been much better if these had been given in more detail, par-

ticularly with regard to the spread or range of the measurements about the steps in the series, and the estimated accuracy of the results. Information of this nature, which is also lacking from all of Seyler's papers on this subject, might be of considerable value in resolving differences of results and opinions in this matter.

The agreement of the data of other observers with Seyler's findings is impressive, but suffers from the fact that it was not obtained independently in other laboratories. It is evident that more independent work on this controversial subject is needed before any generally acceptable decision can be made as to the validity of the step-wise variations of reflectance in coal.

J. T. McCartney.

U. S. Bureau of Mines,
Pittsburgh, Pa.,
Nov. 16, 1951.

THE ORIGIN OF MICHIGAN COPPER DEPOSITS.

Sir: The Michigan copper district has recently been the object of considerable publicity. Substantial government support for exploratory and development projects has been announced and articles on the geology of the district have appeared. I believe a brief discussion pertaining especially to the origin of the copper deposits is in order.

Henry R. Cornwall has made some notable contributions not only to the geology of the Michigan Keweenawan but also to the more general fields of magmatic differentiation and petrogeny. He has taken good advantage of the opportunities for such studies offered by the availability of an immense collection of diamond drill cores through hundreds of lava flows, each flow having been a more or less isolated laboratory in itself. Not only can the differentiation as it affects the more common rock forming minerals be studied, but the local concentrations of the small amounts of metallic ore minerals contained in the lavas may give clues to the processes which are operative in the concentrations which are responsible for some of the ore deposits. Students of these subjects, especially insofar as their investigations deal with lavas, will find his papers informative and stimulating (1).

Mr. Cornwall also treats of the origin of the Michigan copper deposits, into which subject he is led naturally through his studies of rock differentiation, and his treatment is mainly concerned with those parts of the origin of the deposits which he considers as having to do especially with the volcanic activities. I was favored by Mr. Cornwall in that he gave me an early copy of his manuscript for criticism and he is familiar with the points upon which I disagree with him. My comments will bring these out. In addition to these, the reader, expecting a full treatment of the subject, will at times find himself at a loss, because some very important phases are either not mentioned, or they are left to be deduced from rather obscure references. Mr. Cornwall, I know, recognizes these omissions in his present treatment and I hope that he plans to expand the subject when he feels that the proper time has arrived.

In this discussion, I shall also point out some of these omissions and parts of the subject which I regard as essential, but only partially treated.

Specifically, he "postulates that primary concentration of copper, either as native copper or as unstable copper salts formed in the amygdaloids of the flows by syngenetic processes. The primary, syngenetic copper was derived mainly from flows whose original copper content was higher than normal. The primary copper was deposited in the amygdaloids from fumaroles or thermal springs, and in the sediments from playa lakes." Thus, he has primary deposits of copper both in amygdaloids and sediments.

He believes that there is evidence suggesting that among our copper deposits are some of these primary concentrations which were essentially rich enough to constitute ore; as he states it, "the copper has been only slightly reworked by ascending solutions." Such ore deposits are to be classed as syngenetic. While his precise wording mentions only amygdaloid deposits in this connection, I cannot believe this to have been on his part an intentional exclusion of primary sedimentary deposits from his class of syngenetic deposits of commercial grade.

He, then, continues, "Several of the important Michigan deposits, however, were formed by deposition from ascending solutions after the lavas and sediments had been at least moderately tilted. Hot, ascending, hydrothermal solutions formed these deposits by reworking earlier syngenetic copper concentrations in amygdaloids and sediments." These hot solutions were "igneous emanations", and the deposits formed thereby are to be classed as epigenetic.

Thus, the categories into which the deposits might be placed, include both syngenetic and epigenetic. This classification is more complex than that preferred by myself and my former Calumet and Hecla associates. The main points of difference between our ideas and those of Mr. Cornwall are as follows:

1. The Calumet and Hecla classification includes no deposits of syngenetic origin.
2. The Calumet and Hecla ideas of genesis regard the copper as having been brought into the rocks as a direct magmatic contribution by ascending solutions.
3. The Calumet and Hecla ideas do not include any process akin to "lateral secretion". The copper, as it is now found, is essentially as it was originally deposited.
4. The Calumet and Hecla explanation of the chemistry of the deposits accounts for the native state of the copper as due to the oxidation of the accompanying sulphur by the ferric oxide of the rocks through which the solutions passed. Cornwall's idea is that the sulphur was "boiled off" from the surface flows in which the copper was originally deposited.

The test of a scheme of classification is the way in which the things classified fit into it. In classifying the copper deposits of Michigan, one must provide for the several kinds of amygdaloid deposits, the deposits in sediments (conglomerates, sandstones, and shales) and the mass copper deposits in

fissure veins. In all of these are varying amounts of native silver. Furthermore, there are the copper sulphides occurring in the Nonesuch shales, in fissures and elsewhere. There are the massive copper arsenides in fissure vein deposits closely associated with some of the amygdaloid copper deposits. With the copper arsenides there are nickel and cobalt arsenides, also some antimonides.

In addition, one should bring world-wide native copper occurrences into the discussion, as Mr. Cornwall very properly does in calling attention to the common occurrence of the native metal in lavas; but one must also consider the commercial native copper deposits in red sandstones as at Corocoro, Bolivia, where volcanic igneous rocks are absent. In summary, all of the native copper deposits should fit reasonably well into any valid classification and explanation of genesis.

Mr. Cornwall does not mention some of these occurrences and he leaves it pretty much up to his reader to classify those to which he does refer. One discussing the paper critically is thereby placed at a disadvantage. He must guess at how the author would classify specific deposits, and then criticize the guess, running the risk that he has made the wrong guess.

One can infer that Mr. Cornwall would include the Calumet conglomerate orebody, the biggest and richest deposit yet mined in the district, as one of his epigenetic concentrations, but one would like to have a more specific idea as to the locus of the primary disseminations which he assumes to have been leached to provide the copper for it.

Insofar as his source of copper was in primary disseminations in the lavas and sediments, the later hydrothermal solutions were to that extent barren of metal when and where they started. But where did these initially barren solutions acquire the arsenic, antimony, nickel and cobalt, and how did they get these elements into the highly concentrated arsenide fissure deposits?

Over the past several years, there have been numerous references in the press, both technical and non-technical, to the White Pine deposit of the Porcupine Mountain area in the southern part of the district. The principal technical paper has been by Frank Ayer (2), and a short description of the deposit was written by Ira Joralemon (3). While we learn that there is an immense deposit of chalcocite and native copper in shales and sandstones, little is added by these authors to the subject of the origin of the deposit.

One would think that a treatment of the origin of the copper deposits of Michigan would unavoidably include a thorough discussion of the one claimed to be the largest in the district, especially since it has been so conspicuously before the public for several years, but this Mr. Cornwall fails to do. He leaves it to the reader to fit it into his classification.

In a broad way, the Porcupine Mountain region consists of a domical uplift of the sedimentary beds (with a few basalt flows) of the upper part of the Keweenawan, around a core of acidic igneous rocks, at least some of which are intrusive. Around this core, these beds are faulted and folded. Some of the sandstones, shales and amygdaloids of the Lake Shore Trap series are mineralized with copper (and silver). The copper occurs mostly as the native metal in the sandstones and amygdaloids and as chalcocite in the shales. However,

the sandstones have some chalcocite associated with their native copper and the shales have native copper associated with their chalcocite. Cross fissures and strike fissures occur, some of them mineralized with massive native copper and some of them with massive chalcocite. Again, in a broad way, the copper concentration, as I know it, is related at least geographically to the broken rocks around the uplift. In a more detailed way, the intensity of the copper mineralization is in many places definitely greater in the vicinity of the faults and fractures (4). The literature presents specific examples of this relationship and I have seen it in many places underground at the White Pine Mine when Calumet and Hecla operated there. At the outcrop of the mineralized sandstone of the old Carp Lake mine, there are numerous veinlets carrying chalcocite, and there is a suggestion that the copper mineralization in the sandstone beds increases in intensity near these veinlets.

Calumet and Hecla geologists have held that these deposits, native copper and silver, especially in amygdaloids, sandstones and fissure veins, and chalcocite, especially in shales and fissure veins, had the same epigenetic hydrothermal origin as they believe the other deposits of the district to have had. The relationship described, of the intensity of mineralization both on a large scale and in detail, to proximity to faults and fractures has seemed to have been a strong argument in favor of epigenesis. However, accounts of the results of explorations in recent years give a different picture of copper distribution, especially that of the chalcocite in the shale. In contrast to our idea of great variations in intensity of mineralization in the beds, "the remarkable uniformity of ore occurrence and grade over large areas is emphasized" (2). In this connection, the following prediction forty years ago by Alfred C. Lane is of interest. He (Lane) is quoted as believing "that the Nonesuch shales of that vicinity (i.e. the White Pine Mine) in which the copper is distributed in low grade through an immense body, may become as famous, in the way of copper production, as the Mansfield black slates of Germany, in which there has been a copper industry for centuries" (5).

The Porcupine Mountain area has been the scene of repeated attempts to devise methods whereby the deposits could be profitably mined. Ghost camps of different eras are encountered in many places. Calumet and Hecla made the last attempt, having operated the White Pine mine during World War I. Their chief production came from a fairly rich orebody where the sandstones, adjacent to the chalcocite-bearing shale bed, carried native copper. The property was shut down in 1920 and sold some years later.

Operations on the shale bed have presented problems at all stages. The mining is complicated by numerous faults and the milling by the exceedingly fine grain of the ore minerals. Having obtained a concentrate, the final problem is to recover the copper. According to accounts, considerable progress has been made in solving some of these problems in recent years.

Private capital has been wary of financing operations but in view of the tonnage of mineralized ground said to have been developed and the shortage of copper reserves, the government has studied the situation, as it has investigated other projects to increase copper production which are too costly for mining companies to finance. According to recent accounts, the further at-

tempts to solve the problems and, if possible, to produce copper on a large scale, will be financed by a loan of over $57,000,000.

So, perhaps the impact of two world wars and the threat of a third is sufficiently severe that, with the backing of this enormous sum and with the probability of a price guarantee, the interval until these deposits could be worked, as predicted by Lane, Stevens (6) and others, has been materially shortened, and the recurring crop of ghost towns in the area halted. The plan is courageous and developments will be watched with interest.

In any event, I have no firsthand knowledge of results of recent explorations enabling me to appraise the correctness of this great uniformity of mineralization over large areas as reported and, in turn, to consider whether our ideas of the epigenetic origin of all the Porcupine Mountain deposits should be modified for some of them. However, having sat in on some informal discussions between geologists who have had access to these recently obtained data, I find no general agreement among them as to the syngenetic or epigenetic origin of the deposits. Mr. Cornwall gives no clue as to which origin he prefers, but it is interesting to note that he mentions primary deposits of copper in sediments.

A presentation of the evidence, which we have believed indicated an epigenetic origin for these Porcupine Mountain deposits, has been made and some of the references given present more detail. So far as I have discovered, there is little published in favor of syngenetic origin and I do not believe it to have been very seriously advanced. A. E. Seaman, in referring to theories as to the original sources of the copper of the district as a whole, considered the view "that it was deposited in a sulphuretted form, along with the detrital rocks of the series," but in applying this to the Nonesuch shale, he did not believe that it fitted the facts of occurrence as he knew them (7). Until the several geologists who have studied these deposits in the light of the newly acquired data present their arguments, the only safe attitude is to keep an open mind as to their origin.

The reader of the Cornwall papers should refer to a review of them, especially of their treatment of origin, by McKinstry, who treats some phases of the subject not touched upon in my present discussion (8).

The arguments for and against the several modes of genesis of native copper deposits, not only those of Michigan but of Corocoro, Bolivia, the district next in importance, were reviewed five years ago in a paper published in this Journal (9). At that time, it still seemed that the idea of ascending copper-bearing magmatic waters entering the oxidizing environment of ferric iron-bearing amygdaloids and red sediments and precipitating the native metal was adequate to explain the commercial deposits of the world and that the associated arsenides and chalcocite could be explained as due to modifications in the environment. To me, this mode of origin still seems adequate.

T. M. Broderick.

Calumet and Hecla Consolidated Copper Co.,
Calumet, Michigan,
December 11, 1951.

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HOW TO WRITE GEOLOGESE.

Sir: Surely you will agree, provided no witnesses are present, that many of the concepts of geology are relatively simple. But may I inquire what would happen to our prestige if our colleagues in other professions and, most shocking of all, laymen, should begin to suspect this fact? May I therefore invoke the use of your columns to advocate the writing of geological papers in such a manner that students and non-geologists will either (a) despair of trying to read them or (b) be unable to understand them even if they do try? Clearly this is no more than the sound protective strategy long employed so successfully by lawyers and physicians.

Toward achieving this purpose, one simple but rather obvious technique is to build up a highly specialized terminology. Petrographers made notable strides in this direction during the last century, but the younger generation, alas, seems to be losing its grip. Geomorphologists, after a rather slow start, are catching up rapidly. Metamorphic geologists, under the leadership of that naively lucid master of prose, Alfred Harker, were in serious danger of becoming intelligible, but thanks to the Sander school things these days are looking up. For example:

"However, lattice orientation unaccompanied by cognate dimensional orientation can never be attributable to growth from an isotropic blastetrix".[1]

and

"The temperature declines because of cessation of the exothermic chemical and mechanical equilibriopetal processes"[2]

[1] All numbered quotations are from published books and articles but printers' charges have been saved by not setting up the footnote references. Unnumbered quotes are quotes all right but from papers that have not been published (I wonder why).

But stratigraphy deserves the Primrose Medal. A paper telling how to distinguish—pardon me, differentiate—between an orthogeosyncline, an (not *a*, please) eugeosyncline, an exogeosyncline, an autogeosyncline, a zeugogeosyncline, an epieugeosyncline, a taphrogeosyncline, a paraliageosyncline, and a miogeosyncline is admirably calculated to trick those members of the public who move their lips while reading.

Not all of us, unfortunately, are gifted with the linguistic erudition—that insight into *Wortableitung*—which is essential to development of an intricate nomenclature, but any of us with the help of a few judicious hints can learn to construct sentences in such a way that their meaning is not apparent on first reading. The language that is progressing rapidly toward this end may be called, to coin a new term (or isn't it?), GEOLOGESE.

Geologese (alternative spelling: geolo-jeez) closely resembles Federal Prose [3] in general grammar and construction of sentences. It is also akin to Journalese.[4] All three languages bear a superficial but deceptive resemblance to English. Geologese shows, in addition, a marked Teutonic influence. In fact, a sure-fire method of achieving perfect Geologese is to write the paper in German and then translate it literally. But writers lacking a Teutonic sense of word-order may find it almost as easy to learn Geologese as to learn German, though the end-product can never be quite so fine.

Good geologese has the essential merit that it not only baffles non-geologists but offers strenuous mental exercise to geologists themselves; comprehending it and translating it successfully is an intellectual triumph. The reward that it offers is second only to the satisfaction of making an original scientific discovery; in fact some scholars greatly prefer it. After all, what golfer would enjoy playing a course that had no hills or hazards? The successful writer of geologese must provide adequate bunkers, dog-legs, and sand-traps.

One specially ingenious type of dog-leg is the "concealed change of subject" or "how-the-hell-did-we-get-here" sentence. Try this one for example: [5]

"Geological sections on the footwall and hanging wall show correlation of various rocks and vertical movement of 1400 feet. . . ." That seems straightforward enough, but wait! You haven't come to the end of the sentence. It goes on: "is apparent."

See? You have to come back and start over, not missing the dog-leg at the second *"and."*

Here is another cleverly contrived dog-leg: [6]

"As the acidity decreases the field of formation of muscovite . . . ." You read on to see what happens when acidity decreases the field of muscovite, but all you find is "probably extends to a lower temperature." So you go back and start over again.

"All gradations may be observed from massive sulphides without gangue to schist with scattered grains of pyrrhotite or chalcopyrite and vestiges or ghosts, of the schistose structure of the wallrocks . . . ." You might have expected a period here, but the sentence goes on: "are common even in the most massive sulphides." [7]

[3] Example of Federal Prose: The Joint Army-Navy Post-Exchange-Ships Stores Working Committee.

[4] Example: "Steel Contract Boasts Climax Murray Blasts at Red Unions."

Under the heading of sand-traps come contrivances designed not to deflect the course but merely to impede it. Among these are parenthetical references which can interrupt the continuity of a sentence more effectively than hiccups. Thus:

"Granite pebbles are reported from the north (Twenhofel, 1947, p. 75) and south (Jewell, 1939, p. 7) coasts. Some rocks that have been called Silurian (Springdale, Bostwood) (Twenhofel and Schrock, 1937; Espenshade, 1937; MacLean, 1947) are probably Devonian or younger (Twenhofel, 1947)."[8]

After several pages of this, one is guaranteed to forget whether he is reading about the South Jewell Coast or the Younger Twenhofel (who, by the way, is a very nice fellow).

But it is not always necessary to ignore the reader's sensitivities completely. For example, writing "close proximity" makes the meaning perfectly clear to the reader who does not know that the phrase means "close closeness." Similarly, writing *an* hypothesis spares the feelings of any Cockney reader who happens to drop his aitches.

Judicious use of double negatives can achieve the intricacy of a mathematical problem. Take this one for instance:

"This is not to say, however, that argillized sediments are less common along channels of mineralization than elsewhere, for the reverse is true."

Exercise for the reader: Determine what is meant by "the reverse."

Philologists have not yet compiled a complete grammar of the Geologese Language but a few of the main rules are evident:

Rule 1. Never use "of" if you can help it.

Rule 2. Always use nouns in place of adjectives and string together as many of them as possible.

Since Rules 1 and 2 go hand in hand, a single set of examples will illustrate them.

Don't say, "the mineralogy of the copper-iron-sulphur series."

Say, "copper-iron-sulphur series mineralogy."[10] This will start people wondering what "series mineralogy" is anyway.

The phrase "upward-migrating intensity front hypothesis" is a nifty. It is so superb that practically no one could translate it into English even if he were able to distinguish a front hypothesis from a back hypothesis.

Rule 3. Never repeat the same word on any one page. Instead always use "the latter." That will encourage the reader to reread the paragraph in order to find out which was the latter. Application of Rule 3 is especially effective where there are at least three different words to which "the latter" might refer. Example:

"It describes and discusses the relationship of this granite to the country rocks into which it is intruded and to the other rocks of the origin described for the most part by Berkey, Luquer and Ries, Fettke and Agar. The latter occur about the Poundridge granite at distances of from 20 to 30 miles."

This paragraph leaves the reader in intriguing doubt as to whether it is Fettke alone or both Fettke and Agar who occur about the Poundridge granite.

An exceptionally ingenious trick if you can arrange it is to use two *latters* in the same sentence, each *latter* having a different antecedent, as:[11]

"These mixed ores thus appear to be complements of the chalcopyrite ores, the latter being localized along steep boundaries of the ore locus whereas the former are so directly dependent on selective replacement of certain limestones that they characteristically possess the flat dip of the latter."

Considering both the mixed ores and the reader we wind up with the latter as mixed as the former.

Rule 4. A verb agrees with the last preceding noun. Examples:

"The plug of pyroclastics *lie* to the west."[12]

"This differentiation series of igneous rocks from each of the different mining centers *bear* striking resemblances in composition . . . ."[13]

"The course of differentiation as observed in changing mineral composition of the sequence of intrusive rocks *are* shown in Figure 6."[14]

The reason for this rule is founded in simple good taste. Obviously only an illiterate would write: "pyroclastics lies," "center bears," or "rocks is."

Here are some additional models:

"In addition to the effect of the copper ion in the conversion of iron from the ferrous to the ferric state, oxidation of copper-pyrite ores were less likely to yield free sulphuric acid in their oxidation."[15]

"The temperature observed in volcanoes average somewhere between 1000 and 1100."[16]

Rule 5. Never use a simple word where a long one will do. How gauche it would be to speak of a left-handed strike-slip fault! Follow instead the elegance of this model:

"Thus they might be expected to have produced *sinistral transcurrent* faults in about a 170–350 direction and *dextral transcurrent* faults in about a 120–300 direction."[17]

Note also the accuracy of the author's geometry. Does he talk about a 170–230 direction? No, for such a direction would be impossible. Does he talk merely about a 170 direction? No, for the reader might gather the impression that the fault had only a southeasterly strike, whereas this particular fault has a northwesterly strike as well.

But most of this admonition really boils down to Merrill's[18] three general rules: (1) Ignore the reader, (2) Be verbose, vague and pompous, (3) Do not revise.

Yours for a writer coordinated reader comprehension frustration campaign.

NICHOLAS VANSERG.

VANSERG LABORATORIES,
CAMBRIDGE, MASSACHUSETTS.

[18] Merrill, Paul W., The principles of poor writing, Scientific Monthly, vol. 64, pp. 72–74, 1947. See also Masterson, James R., and Phillips, Wendell Brooks, Federal Prose or How to Write in and/or for Washington, University of North Carolina Press, 1948.

REVIEWS

Stratigraphy and Sedimentation. By W. C. KRUMBEIN and L. L. SLOSS. Pp. 497; figs. 123; tbls. 42. W. H. Freeman and Company, San Francisco, Calif., 1951. Price, $5.00.

Those engaged in teaching and practical application of stratigraphy have long sought a satisfactory English-language text. Yet some 35 years of progress in this branch of the geological sciences saw no comprehensive work embodying the newer principles and practices. During this long period of growth, above all in subsurface geology, many new techniques have developed and a great wealth of stratigraphic information, both surface and subsurface, has become available for application to three-dimensional analysis. A vast but widely scattered literature has inevitably evolved. Meeting in large measure an increasingly evident need for treatises and review works, the Krumbein-Sloss book becomes a timely contribution.

Sedimentary rocks are recognized by the authors as fundamental materials of stratigraphy and the stratigrapher is conceived of by them as more dependent on understanding of sedimentation than upon other contributing fields, paleontology ranking a close second. Integration of sedimentation with the subjects of stratigraphy and applied paleontology has been attempted, and in large measure achieved.

By way of orientation the first three chapters deal with the stratigraphic column and stratigraphic procedures. Four chapters devoted to sedimentary rocks follow; these cover properties, classification, description, sedimentary processes and environments, in effect thus forming an abridged sedimentation text. In accordance with the scheme of presentation the chapters on sedimentation form essential background to understanding of terminology employed in the interpretive and analytical portions which constitute the sequel.

For the first time in a stratigraphy text the subject of ecology as related to sedimentary facies and correlation problems is given adequate treatment.

In a sense the unique, and to the reviewer particularly valuable, portion of the book is that comprising the last four chapters in which analytical and interpretive use is made of the foregoing descriptive material. This final section is concerned with the "tectonic framework of sedimentation," "sedimentary tectonics," stratigraphic maps, and paleogeography, subjects the appreciation of which presupposes more than elementary grasp of basic principles. Much controversial matter is involved in these interpretive aspects of stratigraphy and sedimentation. As a matter of fact, treatment of sedimentary tectonics and the tectonic framework is relatively new in America, and the subjects have been largely in the hands of a small but vigorously growing circle of investigators who have served to bring to the fore the significance of such studies in both academic and practical sense.

The authors have treated these topics in such manner as to present various sides of controversial positions, but in as many instances as possible an opinion is expressed favoring one view or another in order to leave the reader with a clearly defined case.

Various tectonic concepts and geosynclinal theories are reviewed impartially prior to presentation of a tectonic classification. As pointed out "The ramifications of geosynclinal theory, as it affects whole concepts of the tectonic framework, have expanded until it now embraces new developments in regional geology, subsurface structure, geophysical data, sedimentation, stratigraphy and other fields of geology, each of which has a bearing on the problem. Until each is evaluated the subject will necessarily remain in a state of flux." In adoption of such terms as "Eugeosyncline," "Miogeosyncline," "Craton," and "Intracratonic Basin," "stable" and "unstable" shelf, the tectonic classification offered by Krumbein and Sloss is more or less in line with that of Stille and of Kay.

Influence of the tectonic framework on sedimentation as inferred directly from the rocks themselves is dealt with under Sedimentary Tectonics, a relatively new branch of petrology. The idea that tectonically controlled major sedimentary cycles, complementary to the Geomorphic Cycle of Davis, are actually recognizable is developed in its various aspects to conform with the conception that "The interplay of tectonism and environment determines the overall characteristics of the accumulating sediment." Tectonic intensity is believed to influence composition of the sediment in such way that for example predominant graywacke, arkose or quartzite may be used as indicators of stages in a major cyclical scheme. The authors believe it possible to resolve problems of regional correlation and general stratigraphic analysis which could not be solved because of conflicting or obscure evidence, by employment of the new frames of thinking introduced by sedimentary tectonics.

The concluding chapters covering stratigraphic maps and paleogeography offer useful explanation with examples of various qualitative and contour-type maps. Illustrations of this kind which endeavor to portray synthetically such elements as geologic structure, thickness of strata, facies change etc. are of value in analysis of large volumes of stratigraphic data, especially where subsurface information is involved. Petroleum exploration and exploitation have supplied the bulk of these data and occasion a need for a manual of three-dimensional interpretive methods adapted to use by the oilfield stratigrapher.

In conclusion the paleogeographic discussion serves as a kind of end-product illustrating the close relationship between all aspects of stratigraphic geology and the subject of paleogeography, which thus serves as a logical historical epitome of the foregoing chapters.

The book undoubtedly serves a very useful purpose, especially for graduate students and practicing stratigraphers handicapped by lack of access to literature. Where the undergraduate has had sufficient general background it may well be of service in a senior course. However, this is not likely to be the case at most institutions, where a stratigraphy course if offered the undergraduate is perhaps best confined in the main to the more elementary facts of regional or descriptive stratigraphy and of historical geology, leaving to graduate study the technicalities and involvements of detailed analysis.

Value of the work is greatly enhanced by the large number of well classified references arranged as supplementary readings at the conclusion of each chapter and in an extensive bibliography (mainly to the American literature) at the end of the volume.

CHARLES W. MERRIAM.

CALIFORNIA INSTITUTE OF TECHNOLOGY,
PASADENA, CALIF.,
Nov. 12, 1951.

Principes de Géologie, 3rd Edit. By P. FOURMARIER. Two volumes; Pp. 1524; figs. 719. Masson & Cie., Paris, and H. Vaillant-Carmanne, Liège, 1950. Price, 6,000 frs.

P. F. Fourmarier has revised and enlarged his comprehensive book on physical geology. This text is at a level which is beyond the reach of the beginning student, but will be very useful to geologists with a broader background in physical geology and at least a moderately good reading knowledge of French. Many of the facts and problems of geology too complex to be outlined in the ordinary geology text and too dispersed in the literature to be understood without considerable research are summarized. The historical background given with most of the subjects helps provide a better understanding of the basic problems involved. The abundant bibliographic references given as footnotes are valuable. The author combines his discussions of the facts and of the problems arising from their interpretation in a well integrated treatment.

For example, in the section on the granite problem Fourmarier gives considerable stress to the historical development of theories and lists important references to the papers of both magmatists and granitisers. He concludes that the facts show that granite has been formed in both ways.

This two-volume work starts with 500 pages of basic facts on the petrology and origin of rocks, including helpful sections on facies, geosynclines, and magmatic differentiation. Next, under "L'Évolution des Roches" the author discusses the features and fundamental causes of folding, faulting, and metamorphism as well as the granite problem. A review of the broad physical features of the continents and of Oceania is grouped with a chapter on tectogenic theories. Sections on climatology, oceanography, hydrology, the geomorphic processes, and the methods used in paleogeography and paleoclimatology round out the book.

The author seems overly conservative in his reluctance to use the term Paleocene. In view of the abundant references, it may seem ungrateful to note that others might have been included. Yet a reference to H. H. Hess is indicated in any discussion of tectogenes, and an annotated discussion of geosynclines seems stunted without references to G. Marshall Kay.

WALTER H. WHEELER.

UNIVERSITY OF NORTH CAROLINA,
CHAPEL HILL, N. C.,
Nov. 10, 1951.

Mechanical Basis for Certain Geologic Structures. By M. KING HUBBERT. Geological Society of America Bull., vol. 62, Pp. 355–372, 1951.

Stress Distribution and Faulting. By W. HAFNER. Geological Society of America Bull., vol. 62, pp. 373–398, 1951.

When students ask for a concise background reference on the mechanical origin of vein-fissures and faults, teachers have been hard put to cite any sound, up-to-date, discussion in the geological literature * beyond the non-mathematical explanations in structural texts and not all of *them* are sound. Hubbert has filled this gap very satisfactorily. Admittedly the principles he discusses should already be familiar to most structural geologists, but unfortunately they are *not* and he has explained them very lucidly. Therefore it is fitting that his article should appear as an intro-

* A partial exception to both of these statements is Anderson, E. M., The Dynamics of Faulting, Oliver and Boyd, London, 191 pp., 1942.

duction to the companion paper by W. Hafner, whose introductory sections, couched in those impeccable but generalized terms so dear to the mathematicians and physicists, require a good grasp of elementary elasticity for their comprehension. Incidentally, Hafner performs a service here in taking geologists to task for using such meaningless phrases as "a stress acting towards the north" and for trying to add stresses vectorially. It's about time! Hafner's main contribution is an analysis of the stress orientation in thrust faulting. Here, for the first time in the geological literature * we find a sound mathematical explanation of the reasons for the curving of many thrust faults. The same principles might profitably be applied by mining geologists to the analysis of certain curving veins.

H. E. McKINSTRY.

HARVARD UNIVERSITY,
CAMBRIDGE, MASS.,
Dec. 14, 1951.

Michigan Copper and Boston Dollars. An Economic History of the Michigan Copper Mining Industry. By WILLIAM B. GATES, JR. Pp. 301. Harvard University Press, Cambridge 38, Mass. Price, $5.00.

Mr. Gates has made a painstaking research into the history of the Michigan Copper District, interpreting it from the economist's viewpoint. Because of its long life and importance, the district is particularly suited for such a study and he believes that his conclusions will prove useful in understanding and predicting corresponding developments in the evolution of other United States extractive industries. He considers such economic histories in four stages: "A period of establishment may be expected in which risks are very great, profits are small—or nonexistent—for all but a few concerns, and the flow of capital into the industry is heavy and is very largely lost to the immediate investor. The next period will be one of substantial growth, both in scale of enterprise and number of successful units, and again the flow of capital is likely to be toward the industry, but this time primarily in the form of reinvestment of earnings, rather than new market flotations. Growth is followed by maturity, a period when new investment opportunities are unpromising and output remains fairly stable. An increasing interest in consolidation schemes may be expected, and earnings are likely to be exceptionally high and to be paid out as made. Finally, decline of the industry brings with it inability to earn enough to meet depletion and even depreciation charges, and an effort to rescue as much sunk capital as possible, often through planned shifts by the companies into other stages of the metals industry."

It is interesting that S. G. Lasky also has just published a study in which he fits the growth and decay of mineral industries into a similar pattern as expressed by a mathematical curve (E. & M. J., Aug. 1951). The curve for Michigan copper production throughout the past resembles his curve.

Mr. Gates gives voluminous source references, and he has made most interesting reading, based upon the dull statistical tabulations (which he includes in the appendix). For a long time, the district was the largest copper producer in the world, and in presenting its economic history, the author, incidentally, covers much of the world history of copper mining. Because of the general application of his deductions to an understanding of the economics of the mining industry, the book deserves a broad technological circulation. His access to Calumet and Hecla files in Boston has enabled him to reveal facts hitherto unavailable. For instance, the reviewer, after many years as geologist for Calumet and Hecla, just learns that in 1895 his company "joined with Anaconda in keeping two young geologists in

the field looking for promising new claims," and that in 1897, the company "began sending representatives all over the west and as far afield as Mexico, British Columbia, and Alaska."

Woven into his story are the problems and struggles of labor relationships, considered both from the standpoints of company managements and the men. Sociologically, the district was for many years a one-industry area and there was little escape from paternalism in business, educational, political, religious, and social relationships, since all aspects of community life were dependent upon the income from the mines. As time went on and the mining shrunk, these various phases of community life were forced to adjust themselves accordingly, and the pains of this shrinking are described.

The reviewer has not checked the fundamental facts upon which conclusions are based, but he has no reason to question them. There are a few incidental statements which should be corrected. Thus, the Osceola Company did not work *the* underlying amygdaloid after abandoning attempts on the Calumet conglomerate. Instead they worked the fifth amygdaloid below the conglomerate, some hundreds of feet in its footwall. The Allouez Company worked the Allouez, not the Calumet, conglomerate. The implication that the copper deposits become leaner in depth *because of the depth factor* needs more lengthy discussion, perhaps beyond the scope of the book.

During the period 1919–1938, there was only one of the richer lodes (the Baltic) exhausted, not a number of them as stated. The Kearsarge amygdaloid is still being mined, and the other ore bodies still continue in depth, even though economic considerations have caused the suspension of operations upon them.

It is stated that the Calumet conglomerate "was to prove one of the richest copper deposits in the world." While the recovery from the rock mined during the first twenty years of operation on this lode was well over 4 percent copper, its average over its entire life to date was 2½ † percent. This is high compared with the porphyry coppers, but not high compared with others such as Magma, Bisbee, and Jerome, in the 5 to 6 percent class, Globe over 4 percent and Butte from 3 to 4 percent, in the United States, or with Noranda and Rhodesia, to name some foreign deposits.

Illustrations, although few, are good, but their titles are inadequate. Readers should be informed that early ore dressing methods, batteries of stamps, underground operations on the Calumet conglomerate, and an electrolytic plant are shown.

In general, the non-technical reader probably can read the book with ease and sustained interest. The mining engineer and geologist, however, may have a feeling of irritation, an effect which Mr. Gates could have easily avoided. Most of his offenses arise from two causes: First, he depends in part for his usage of terms upon a glossary published nearly fifty years ago, and he thereby perpetuates errors which we technologists have striven to correct and forget. Second, he refuses to accept and use simple terminology which those in the mining industry have adopted.

Perhaps most irritating is his insistence on perpetuating obsolete local usages for the terms "mineral" and "ore." Mineral is an old name for concentrate and, in most cases, he uses the word with that obsolete meaning. However, he also uses it with other meanings such as ore in general (as a "mineral deposit"), the ore mineral (in this case native copper), and in places his meaning is the precise one as employed by the mineralogist and geologist. The word "ore" he avoids as he would the plague, since he subscribes to an early local idea that an ore is a mineral in which the metal is combined (he says "contaminated") with some other element such as sulphur. Hence, native copper-bearing rock would not be "ore,"

and he uses various clumsy devices, such as "mineral body" or "material," to avoid the term "ore body."

Other errors, or oddities in expression, are as follows: Rock is "blown loose" instead of broken or stoped; "finely disseminated conglomerate" instead of finely disseminated copper in conglomerate; skips only run in inclined shafts, not in vertical shafts; copper "fields" instead of districts.

The few references to the geology of the district should be more carefully phrased. Thus it is said that "The Peninsula comprised—3,000 miles of territory within which were scattered some 400 lava flows and conglomerate and sandstone beds" and that the mass fissure deposits were "geological freaks." Instead of saying that certain lodes dip steeply, Mr. Gates says they "slant down rapidly." The Calumet conglomerate is described as a "tough puddingstone." The term is seldom used today, but even so, the Calumet conglomerate is not truly a puddingstone, nor is it tough. It is brittle, although hard.

The work on the book was mostly done at the University of Chicago; it was printed by the Harvard University Press; distributed in Great Britain by the Oxord University Press, and is copyrighted "by the president and fellows of Harvard College." With such endorsement, one would think that somewhere along the line the manuscript would have been so edited that ordinary errors and peculiarities of word usages would have been corrected. Among these are such expressions as: most marginal, more indigenous, how permanent (a thing might be), new innovation, residual left, react back, and most unique.

Mr. Gates steers clear of "gobbledegook" pretty well. He does say "top management," "margin of profit" (and one wishes that he would widen it instead of "raise" it); he "highlights" things; he "plows back"; he has the "over-all picture"; he speaks of a "dynamic," and of the several "games" such as the "import game."

The function of the historian is mainly to record and interpret the past and, as a historian in economics, Mr. Gates has made a valuable contribution. The exploration geologist, on the other hand, is largely concerned with the future, and, as such, the reviewer must state that the changing situation with respect to supply and demand for domestic copper leads him to believe that the district has many years of life ahead, even though the mining may be on the lower grade native copper deposits long known. Furthermore, the geological situation is such that undiscovered deposits of the higher grades mined in the past, should exist, only awaiting discovery by persistent exploration. Perhaps to the four periods envisaged by Mr. Gates, the future historian will add a fifth, which might be called the stage of Revival.

THOMAS M. BRODERICK.

CALUMET AND HECLA CONSOLIDATED COPPER COMPANY,
CALUMET, MICHIGAN,
Jan. 10, 1952.

Proceedings of the Fourth Empire Mining and Metallurgical Congress, Great Britain, July 9th–23rd, 1949. 2 Volumes. Edited by F. HIGHAM. Pp. 1,139; 87 illustrations. 436 Salisbury House, Finsbury Circus, London, E. C. 2, England, 1950. Price, £2.

These two volumes represent the proceedings of the Fourth Empire Congress held in Great Britain in 1949. The papers deal with mineral resources, mineral industry and economics, prospecting, physiological and psychological effects of heat and humidity on workers in deep mines and metallurgical works, mineral dressing, and metallurgy.

The papers of chief interest to geologists and miners are: Mineral Industry of Australia—With Particular Reference to the Past Twenty Years, by P. B. Nye, I. C. H. Croll and D. R. Dickinson; Some Notes on the Mineral Resources (Excluding Coal) of the Union of South Africa, by A. R. Mitchell; Changes in Canada's Mineral Resources During the Past Ten Years, by G. C. Monture; The Mineral Resources of Malaya and Other Far Eastern Countries, by Sir Lewis L. Fermor; The Mineral Resources of the British West African Colonies, by N. R. Junner; The Mineral Resources of the East African Colonies, by Sir Edmund O. Teale; Mineral Resources of India, by D. N. Wadia; Significant Changes in the Known Position of the Mineral Resources of Southern Rhodesia During the Past Twenty Years, by J. C. Ferguson; The Mineral Resources of Other Empire Territories, by E. H. Beard; Aerial Photography in Petroleum and Mineral Prospecting, by A. A. Fitch, D. F. Christie, W. E. Johnstone, and G. Whittle; Modern Methods of Mineral Exploration in South Africa, by Louis T. Nel, D. J. Simpson, and John de Villiers; Mineral Exploration in Australia, by C. J. Sullivan; Modern Methods of Mineral Exploration in Canada, by Franc R. Joubin; Coal Resources of the British Commonwealth, by C. Augustus Carlow; The Characteristics of the Empire Coals and Their Bearing on the Industrial Potential of the Empire, by Robert Foot; Metallurgical and Mining Problems in Atomic Energy, by Sir John D. Cockcroft; Miners as Pioneers, by Charles Camsell.

As will be seen from the above papers these two volumes give a broad picture of many phases of the mineral occurrence, resources, and industries of the British Commonwealth.

Principles of Human Geography, 6th Edit. By ELLSWORTH HUNTINGTON AND SUMNER W. CUSHING; revised by EARL B. SHAW AND JAMESON MACFARLAND. Pp. 805; pls. 2; figs. 245. John Wiley & Sons, Inc., New York, Chapman & Hall, Ltd., London, 1951. Price, $6.25.

This old warhorse of geography first appeared in 1920, 1922, and 1924 by Ellsworth Huntington and Sumner W. Cushing; the 1934 and 1940 editions were by Ellsworth Huntington and Francis D. Harrower. This 6th edition by Mr. Shaw retains a number of the interesting chapters of the earlier editions and has added several new ones and made alterations and additions to many others. The purpose of the book is to provide a comprehensive textbook for elementary students. It takes up first the physical background in 6 chapters dealing with examples of human geography, the earth and its motions, maps and climate. It then deals with man's relation to land forms, soil, minerals, power, climate, vegetation, and to man himself. The last 3 chapters deal with the countries of the world. Many new illustrations have been added. This edition, like its predecessors, is readable and enjoyable and should continue to be one of the leading textbooks.

South African Scenery—A Textbook of Geomorphology, 2nd Edit. By LESTER C. KING. Pp. 379; pls. 267; figs. 79; 1 colored map. Oliver and Boyd, Ltd., Edinburgh, 1951. Price, 45/– net.

This new edition has undergone considerable revision although the general order of treatment remains the same. This book really is a nicely illustrated and well written textbook of geomorphology, drawing its text matter and illustrative material from South Africa, and to a less extent, central and east Africa. It is quite a vivid presentation of an unusually highly diversified and interesting topog-

raphy. Naturally the author goes into the ancient glaciation of southern Africa as well as the modern glaciation of the central African mountains.

The author takes up weathering, the river cycle, the hillslope and landscape cycles, the work of wind and the arid cycles, underground water, sea erosion, volcanoes, topographic effects of land movement, buried and ancient topographies, and the geomorphology of southern Africa and the African territories. This is a readable book that will be enjoyed by geologists and geographers and which will serve as a valuable textbook.

BOOKS RECEIVED.

CHARLES H. SMITH.

U. S. Geological Survey—Washington, D. C., 1951.

Prof. Paper 226. The Geology and Geography of the Paunsaugunt Region, Utah. HERBERT E. GREGORY. Pp. 116; pls. 5; figs. 63. Price, $2.25. *Survey of parts of Garfield and Kane Counties, South-Central Utah. Stratigraphy, structure, and physiography described in detail.*

Bull. 963-E. Coal Investigations in South-Central Alaska, 1944–46. F. F. BARNES, CLYDE WAHRHAFTIG, C. A. HICKCOX, JACOB FREEDMAN, AND D. M. HOPKINS. WITH A SECTION ON CLAY DEPOSITS ON HEALY CREEK BY E. H. COBB. Pp. 76; pls. 14; figs. 6. Price, $1.50. *Contains reports on the following areas—the Nenana coal field, Matanuska Valley, Broad Pass Station, and Homer.*

Bull. 974-D. Report of the Hawaiian Volcano Observatory for 1948 and 1949. R. H. FINCH AND GORDON A. MACDONALD. Pp. 30; figs. 11; tbls. 2. Price, 20 cts. *Describes equipment, investigations, eruption of Mauna Loa in 1949, and possibility of diverting lava flows by bombing.*

Bull. 975-A. Geology of the Huancavelica Quicksilver District, Peru. ROBERT G. YATES, DEAN F. KENT, AND JAIME FERNANDEZ CONCHA. Pp. 45; pls. 6; figs. 5. Price, $1.25. *Once world's largest producer of quicksilver, area has produced little in last hundred years. Future depends on exploration of old workings now inaccessible.*

Bull. 981-B. Geophysical Abstracts 145 April–June 1951. MARY C. RABBITT AND S. T. VESSELOWSKY. Pp. 57. Price, 25 cts. *Abstracts Nos. 12701–12890.*

Water Supply Papers

1079-D. Ground-Water Resources of the Republic of El Salvador, Central America. A. N. SAYRE AND G. C. TAYLOR, JR. Pp. 70; pl. 1; fig. 1. Price, $1.00. *Geologic and hydrologic studies of water supply as a part of the program of the Health and Sanitation Division of El Salvador.*

1110-A. Alluvial Fills Near Gallup, New Mexico. LUNA B. LEOPOLD AND C. T. SNYDER. Pp. 19; figs. 8. Price, 15 cts. *A study of erosion and deposition in late Pleistocene and Recent time.*

1126. Water Levels and Artesian Pressure in Observation Wells in the United States in 1948. Part 1. Northeastern States. UNDER THE DIRECTION OF C. G. PAULSEN. Pp. 420; figs. 16. Price, $1.00.

1128. Water Levels and Artesian Pressure in Observation Wells in the United States in 1948. Part 3. North-Central States. UNDER THE DIRECTION OF C. G. PAULSEN. Pp. 325; figs. 11. Price, 70 cts.

1148. Surface Water Supply of the United States, 1949. Part 8. Western Gulf of Mexico Basins. UNDER THE DIRECTION OF C. G. PAULSEN. Pp. 375. Price, $1.00.

Oil and Gas Investigations Map OM 121. Geology of the Region from Socorro and San Antonio East to Chupadera Mesa, Socorro County, New Mexico. (In 2 sheets.) R. H. WILPOLT, A. J. MCALPIN, A. D. ZAPP, A. A. WANEK, AND R. L. BATES. Figs. 6. Price, 80 cts. *Colored geologic maps, scale 1" = 1 mile; 6 graphic sections.*

TEM-102-A. Investigations in the Wood Mine, Colorado. ROBERT U. KING. Pp. 1.

TEM-146-A. Results of Diamond Drilling, Merry Widow Claim, White Signal, Grant County, New Mexico. H. C. GRANGER AND H. L. BAUER, JR. Pp. 11; figs. 2.

TEM-9-B. Treasure Hill Area, Larimer County, Colorado. DONALD G. WYANT. Pp. 3; figs. 2. *Little or no detectable radioactivity in area.*

U. S. Atomic Energy Commission—Oak Ridge, Tennessee, 1951.

RMO-754. Geology and Ore Deposits of Mesa V, Lukachukai District, Arizona. JOHN W. KING. Pp. 17; pls. 2. *Carnotite and vanoxite mineralization of ore grade in Morrison sandstones.*

RMO-755. Reconnaissance of Red Rock District, Cove Mesa, and Kinusta (Tree) Mesa, Arizona. JOHN W. KING. Pp. 11; pls. 3.

U. S. Bureau of Mines—Washington, D. C., 1951.

Vol. 20, No. 2. World Retail Prices and Taxes on Gasoline, Kerosene, and Motor Lubricating Oils. REGINA B. SHEEHAN. Pp. 15. *Tables of prices in representative cities during January–March, 1951.*

U. S. Soil Conservation Service—Lincoln, Nebraska, July, 1951.

Relation of Sedimentation to Accelerated Erosion in the Missouri River Basin. LOUIS M. GLYMPH, JR. Pp. 23; figs. 3; tbls. 4. *Present erosional problems outlined, and some conservation measures described.*

Library of Congress—Washington 25, D. C., November 30, 1951.

Manchuria—An Annotated Bibliography. COMPILED BY PETER A. BERTON. Pp. 187. Price, $1.30. *A selective coverage of available literature, with emphasis on Manchurian economy.*

North American Geosynclines. MARSHALL KAY. Pp. 143; figs. 20; pls. 16. Geol. Soc. America Mem. 48. New York, November, 1951. *Descriptions of geosynclines of all types, their stratigraphy and its interpretation, and application to the growth of continents. Eugeosynclines formed in regions like modern island areas which represent areas of thin sial.*

Temperature-Pressure Research of Hydrothermal Mineral Deposits. F. G. SMITH. Pp. 93. Progress Rept. Vol. 3, Pt. 6, November 30, 1951. *A survey of the literature relating to methods of determining the temperature and pressure of deposition of minerals from measurements of foreign inclusions. 350*

references dating from 1822 to the present are listed and their pertinent results given. Concludes with a critical summary of present state of knowledge under 4 headings: (1) types of inclusions in crystals; (2) formation of inclusions; (3) solutions of mineral growth; (4) inclusion geothermometry.

Range Management. A. W. SAMPSON. Pp. 570; figs. 111; tbls. 38; pls. 2. John Wiley & Sons, Inc. New York, 1952. Price, $7.50. *In 4 parts entitled, range management in perspective, native range forage plants, improvement and management of range and stock, protection of range resources and range livestock.*

Aluminum for Defense and Prosperity. DEWEY ANDERSON. Pp. 40. *The Public Affairs Institute. Washington, D. C., 1951. Price, 50 cts. Study of issues involved in a sound national policy.*

Differential Thermal Analysis. W. J. SMOTHERS, YAO CHIANG, AND ALLAN WILSON. Pp. 44. University of Arkansas, Research Ser. 21, Fayetteville, Arkansas, November, 1951. *Brief description and history of method. Index of authors and index of materials which have been analyzed are also included.*

Geology and Ground-Water Resources of Choctaw County, Alabama. L. D. TOULMIN, P. E. LA MOREAUX, AND C. R. LANPHERE. Pp. 197; figs. 23; tbls. 4; pls. 11. Alabama Geol. Survey Special Rept. 21 and County Rept. 2, University, Alabama, 1951. *Descriptions of formations and their water-bearing properties.*

Arizona Zinc and Lead Deposits. Pp. 118; figs. 25. Arizona Bureau of Mines, Geol. Ser. 19, Bull. 158, Pt. 2, Tucson, Arizona, July, 1951. Price, 60 cts. *Detailed descriptions of the following districts—Dragoon Mountains, Swisshelm, Huachuca Mountains, Oro Blanco of Ruby, Empire, Bunker Hill, Banner, Silver, Eureka, and Castle Dome.*

California Division of Mines—San Francisco, 1951.

Bull. 154. Geologic Guidebook of the San Francisco Bay Counties—History, Landscape, Geology, Fossils, Minerals, Industry, and Routes of Travel. UNDER THE DIRECTION OF OLAF P. JENKINS. Pp. 392; many illustrations. *Contains a sectional map covering 12 counties, a series of geologic travel logs, and numerous well illustrated separate articles covering history, science, and natural resources.*

Special Rept. 7-A. Gem- and Lithium-Bearing Pegmatites of the Pala District, San Diego County, California. RICHARD H. JAHNS AND LAUREN A. WRIGHT. Pp. 72; figs. 35; pls. 13. Price, $2.50. *Detailed descriptions of pegmatites, their economic features, and selected mines. Most pegmatites are zoned, with gem quality spodumene occurring only in cores.*

Special Rept. 9. Type Moreno Formation and Overlying Eocene Strata on the West Side of the San Joaquin Valley, Fresno and Merced Counties, California. MAX B. PAYNE. Pp. 29; figs. 11; pls. 5. Price, 60 cts.

Special Rept. 12. Hydraulic Filling in Metal Mines. WILLIAM EWART LIGHTFOOT. Pp. 28; figs. 15. Price, 50 cts. *Properties, techniques, and costs described. Extensive bibliography.*

Special Rept. 13. Geology of the Saline Deposits, Bristol Dry Lake, San Bernardino County, California. HOYT S. GALE. Pp. 21; figs. 2; pl. 1. Price, 35 cts. *Gypsum, sodium chloride, calcium chloride, and celestite deposits.*

Special Rept. 14. Geology of the Massive Sulfide Deposits at Iron Mountain, Shasta County, California. A. R. KINKEL, JR. AND J. P. ALBERS. Pp. 19; figs. 6; pls. 6. Price, 75 cts. *Lenses of massive pyrite with chalcopyrite, sphalerite, and minor gold and silver localized where a steep feeder channel cuts folded porphyritic rhyolite near the crest of a large anticlinorium.*

Late Cenozoic Erosional History of the Raton Mesa Region. WILLIAM S. LEVINGS. Pp. 111; figs. 31; pls. 16. Colorado School of Mines Quart., Vol. 46, No. 3. Golden, Colorado, July, 1951. Price, $2.50. *Study of age and mode of origin of a high level, gravel-strewn, late Miocene or early Pleistocene surface. Origin by lateral planation.*

Illinois Geological Survey—Urbana, 1951.

Circ. 175. Mineral Resource Research and Activities of the State Geological Survey, 1950–1951. M. M. LEIGHTON. Pp. 38; figs. 19. *Reprinted from the Annual Report of the Chief to the Director, Department of Registration and Education for Fiscal Year 1950–1951.*

Rept. Inv. 156. Geology and Coal Resources of a Part of the Pennsylvanian System in Shelby, Moultrie, and Portions of Effingham and Fayette Counties. ERNEST P. DU BOIS. Pp. 32; figs. 9; pls. 5.

Rept. Inv. 157. An Economic Study of Fuels in Manufacturing. WALTER H. VOSKUIL. Pp. 28; tbls. 26.

Indiana Department of Conservation—Bloomington, 1949–1951.

Progress Rept. 3. Crushed Stone in Indiana. JOHN B. PATTON. Pp. 47; pl. 1. Price, 50 cts. *Outline of producing formations and tabulation of quarries.*

Bull. 4. Glacial Sluiceways and Lacustrine Plains of Southern Indiana. WILLIAM D. THORNBURY. Pp. 21; figs. 3; pls. 2. Price, 50 cts.

Bull. 5. Glacial Geology of Wabash County, Indiana. WILLIAM J. WAYNE AND WILLIAM D. THORNBURY. Pp. 39; fig. 1; pls. 7. Price, $1.00.

Guide Bk. 3. Silurian Formations and Reef Structures of Northern Indiana. COMPILED BY R. E. ESAREY AND D. F. BIEBERMAN. Pp. 19; figs. 2; pls. 2. Price, $1.00.

Guide Bk. 4. Stratigraphy Along the Mississippian-Pennsylvanian Unconformity of Western Indiana. COMPILED BY R. E. ESAREY, D. F. BIEBERMAN, AND R. A. BIEBERMAN. Pp. 23; figs. 2; pls. 3. Price, $1.00. *Itinerary, stratigraphic sections, and descriptions of formations.*

Guide Bk. 5. Pennsylvanian Geology and Mineral Resources of West Central Indiana. COMPILED BY CHARLES E. WIER AND RALPH E. ESAREY. Pp. 34; pls. 4. Price, 50 cts.

Petroleum Exploration Maps, Nos. 12a, Martin County; 23a, Knox County; 24a, Monroe County; 25a, Lawrence County; 26a, Daviess County; 27a, Orange County; 28a, Crawford County; 29a, Washington County; 30a, Harrison County. COMPILED BY DONALD E. HYER, G. L. CARPENTER, DALLAS FIANDT, AND W. D. PENNINGTON. *Showing well locations. Scale, 1 in. = 1 mile.*

Kansas University and Geological Survey—Lawrence, 1951.

Bull. 90, Pt. 8. Beneficiation of Kansas Number Four Salt. FRANK W. BOWDISH. Pp. 25; figs. 2; pl. 1. *Descriptions of tests, with proposed flow sheets and cost estimates.*

Map. Kansas Mineral Resources. PREPARED BY J. C. FRYE, E. D. GOEBEL, A. HORNBAKER, J. JAEGER, J. M. JEWETT, V. WITHERSPOON, R. O. KULSTAD, G. MUILENBERG, N. PLUMMER, W. H. SCHOEWE, AND A. M. WHITE. *Approximate scale, 1 in. = 10 miles.*

Geology, Mineral Resources, and Ground-Water Resources of Chase County, Kansas, Vol. 2. Pt. 1, Rock Formations of Chase County. RAYMOND C. MOORE, JOHN MARK JEWETT, AND HOWARD G. O'CONNOR. **Pt. 2, Mineral Resources of Chase County.** HOWARD G. O'CONNOR, JOHN MARK JEWETT, AND R. KENNETH SMITH. **Pt. 3, Ground-Water Resources of Chase County.** HOWARD G. O'CONNOR. Pp. 49; figs. 3; tbls. 12. *First of a series of reports on eastern Kansas counties, consisting primarily of maps, but containing brief descriptive stratigraphy, discussions of groundwater and other useful materials.*

Thirty-Ninth Annual Report to The Governor of the State of New Mexico. THE STATE INSPECTOR OF MINES. Pp. 39; pls. 8. *Albuquerque, New Mexico, 1951.*

Ohio Department of Natural Resources—Columbus, 1951.

Bull. 49. Limestones of Eastern Ohio. RAYMOND E. LAMBORN. Pp. 377; tbl. 1; pls. 2. Division of Geological Survey. Price, $2.06. *Character, thickness, and distribution of limestone formations and a detailed study of the composition, described by counties.*

Rept. Inv. 9. 1950 Investigation of Lake Erie Sediments, Vicinity of Sandusky, Ohio. HOWARD J. PINCUS, MARJORIE L. ROSEBOOM, AND CURTIS C. HUMPHRIS. Pp. 37; figs. 25; tbls. 2. Division of Geological Survey. *First of a series of reports on geological processes at work in and around Lake Erie.*

Rept. Inv. 12. Illinoian and Wisconsin Drift of the Southern Part of the Grand River Lobe in Eastern Ohio. GEORGE W. WHITE. Pp. 11; figs. 2; pl. 1. Division of Geological Survey. *Reprinted from G.S.A. Bull., Sept., 1951.*

Rept. Ser. 4. Pp. 28; figs. 5; tbls. 8. Division of Geological Survey. *The Orleton Farms Mastodon, by Edward S. Thomas. Geological Situation of the Orleton Farms Mastodon, by Richard P. Goldthwait. Pollen Spectra Associated with the Orleton Farms Mastodon Site, by Paul B. Sears and Kathryn H. Clisby. Molluscan Faunas of the Orleton Mastodon Site, Madison County, Ohio, by Aurele La Rocque. Tooth-Marks on Bones of the Orleton Farms Mastodon, by Albert E. Wood.*

List of Publications and Maps on the Geology and Mineral Resources of Ohio. Pp. 16. Division of Geological Survey.

Oregon Department of Geology and Mineral Industries—Portland, 1951.

G.M.I. Sht. Pap. 21. Lightweight Aggregate Industry in Oregon. RALPH S. MASON. Pp. 23; fig. 1; tbl. 1. Price, 25 cts. *Pumice, diatomite, perlite, volcanic tuff and cinders, and expanded shale deposits described.*

G.M.I. Sht. Pap. 22. Preliminary Report on Tungsten in Oregon. HAROLD D. WOLFE AND DAVID J. WHITE. Pp. 24; figs. 4; tbls. 3. Price, 35 cts. *Description of deposits occurring in contact zones between calcareous and intrusive rocks.*

Canada Department of Mines—Ottawa, 1950–51.

Mem. 257. Geology of a Southwestern Part of the Eastern Townships of Quebec. H. C. COOKE. Pp. 142; figs. 21; colored geol. map, scale 1 in. = 2 miles. Price, 75 cts. *Concerned mainly with the complex structural and stratigraphic relations of Cambrian to Devonian rocks. Descriptions of ultrabasic to granitic rocks, and associated metalliferous and industrial mineral deposits.*

Mem. 258. Pierre Greys Lakes Map-Area, Alberta. E. J. W. IRISH. Pp. 66; figs. 2; pl. 1; colored geol. map 996A, scale 1 in. = 1 mile. Price, 75 cts. *Represents a cross-section of most of Foothills belt in that part of northwestern Alberta traversed by Muskeg River. Oil possibilities and coal of interest.*

Ontario Department of Mines—Toronto, 1951.

59th Annual Report, Vol. LIX, Pt. VI, 1950. Geology of McElroy and Part of Boston Townships. E. M. ABRAHAM. Pp. 66; figs. 7; photos. 12; colored geol. map, scale 1 in. = 1,000 ft. *Another of a series on geology of Kirkland Lake–Larder Lake area. Keewatin volcanics and Timiskaming sediments, cut by Haileyburian, Algoman, and Keweenawan intrusives. Timiskaming sediments of areas form south limb of a major synclinal structure, the north limb of which lies north of the Larder Lake break. Detailed descriptions of gold properties.*

Map 1951-7. *Colored geological map. Scale, 1 in. = 1,000 ft.*

Australia Bureau of Mineral Resources—Melbourne, 1951.

The Australian Mineral Industry, Vol. 4, No. 1. Pp. 28; many tbls. *Section on industrial abrasives.*

The Australian Mineral Industry 1950 Review. Pp. 186. *Statistics.*

Western Australia Geological Survey—Perth, 1949–1950.

Bull. 102. Greenbushes Mineral Field. R. A. HOBSON AND R. S. MATHESON. Pp. 219; figs. 17; pls. 9. *Detailed descriptions of general geology and ore deposits of a cassiterite-producing area.*

Bull. 104. Some Economic Aspects of the Principal Tantalum-Bearing Deposits of the Pilbara Goldfield, North-West Division H. A. ELLIS. Pp. 93; figs. 3; pls. 9. *Quantitative data on the commercial availability of tantalum-bearing minerals (eluvial, alluvial, and lode) at Wodgina, Strelley, Labba-Labba, and Pilgangoora.*

Industrial Diamond Trade Names Index. COMPILED BY INDUSTRIAL DIAMOND INFORMATION BUREAU AND INDUSTRIAL DIAMOND REVIEW. Pp. 64. N.A.G. Press Ltd., London, 1951–52. Price, 3/6d.

Minerales. Nos. 37, 38. Pp. 66. Inst. Ing. Chile Rev., Santiago, 1951. *Includes papers on drilling in the Teresita-Copiapo mine, the extractive metallurgy of zinc, and new mining laws of Perú.*

Actividades Petroleras, Nos. 61–63. Pp. 17. Ministerio de Minas e Hidrocarburos, Caracas, Venezuela, 1951. *Drilling, production, and refining statistics.*

Introduction à l'Etude de la Métallogénie et à la Prospection Minière. PIERRE DESPUJOLS AND HENRI TERMIER. Pp. 200; figs. 26. Division des Mines et de la Géologie, Service Géologique, Notes et Mémoires 66. Rabat, 1946. Price, 200 fr. *Chapters on scientific tendencies in prospecting; the primary distribution of vein deposits and its interpretation; the lessons of thermodynamics, differentiation, and secondary phenomena; classification of deposits; surface alteration; prospecting.*

Les Bauxites de l'Europe centrale (Province dinarique et Hongrie). JEAN-GODEFROY DE WEISSE. Pp. 162; figs. 14; tbls. 5; pls. 3. Thèse présentée à la Faculté des Sciences de l'Université de Lausanne. Lausanne, 1948. *Descriptions of deposits in Dinarique province, southeast Alps, and the central Hungary massif—relation between bauxite, manganese, and coal deposits—constituents and genesis of bauxite. Bauxite forms from limestones or dolomites by gradual elimination of silica controlled by pH and climate. Solubility of silica increases under alkaline conditions while solubility of iron oxide and alumina decreases.*

Comptes Rendus du Congrès Scientifique—Elisabethville, 1950. Comité Spécial du Katanga, Bruxelles.

Vol. IV, Tome I. Travaux de la Commission Agricole, Zootechnique et Forestière. Pp. 264. 1950. *Many papers of mainly agricultural interest.*

Vol. IV, Tome II. Travaux de la Commission Agricole, Zootechnique et Forestière. Pp. 201. 1950. *Papers on forestry and zoology.*

OP. 17. Les Cadres de la Géologie du Katanga. MAURICE ROBERT. Pp. 45; fig. 1. 1951. *Outlines of the geology of Katanga.*

OP. 18. Géologie du Katanga, les Formations du Manteau Continental. MAURICE ROBERT. Pp. 25. 1951. *Formations of the continental mantle.*

OP. 19. Géologie du Katanga, les Formations du Soubassement Ancien. MAURICE ROBERT. Pp. 35. 1951. *Formations of the basement complex.*

Annales Géologiques du Service des Mines—Paris, 1948, 1950.

No. XIV. Ammonites Neocrétacées du Menabe (Madagascar). MAURICE COLLIGNON. Pp. 101; pls. 32. *Neocretaceous ammonites of Menabe—Part I—Texanitidae.*

No. XVII. Recherches sur les Faunes Albiennes de Madagascar. MAURICE COLLIGNON. Pp. 85; pls. 14. *In 3 parts—the albian echinoids of Ambarimaninga, albian fauna of Komihevitra, and albian fauna of Mokaraha.*

Annales de la Société Géologique de Pologne, Vol. XX, Fasc. 3. Pp. 107. Cracow, 1951. *5 papers: Stratigraphic position of the Eemien deposits in the lower Vistula area; Eemien foraminifera of Tychnowy; Eemien interglacial on the lower Vistula; problems of Eocene transgression in Zatra; ultramicroscopic investigations of minerals with regard to their origin. Latter paper stresses role of bacteria in mineral formation, citing Rio Tinto pyrite masses as an example.*

Abhandlungen des Geologischen Dienstes Berlin—1951.

Heft 81. Schwermineral-Seifen an der Mecklenburgischen Ostseekuste. KURD VON BULOW. Pp. 63; figs. 19; tbls. 19. Archiv für Lagerstatten-

forschung. Price, 9.50 DM. *Alluvial deposits of heavy minerals on the Mecklenburgian shore of the Baltic Sea. A study of the origin and behavior of deposits under varying meteorological and shore line conditions.*

Heft 220. Über die Brauchbarkeit einer deutschen und einer sowjetischen Feldmethode zur Bestimmung des "Rohton"-Gehaltes der Boden. Über eine Feldmethode zur Bestimmung des natürlichen Wassergehaltes von Boden. Das hydrologische Dreieck. Frostgefahrliche Boden, ihre Erkennung und ihr Verhalten bei Strassen- und Hochbauten. Pp. 40; figs. 9; tbls. 14. Price, 4.20 DM. *The usefulness of a German and Soviet field method for determining the admixture of clay particles in soils, by R. Kohler. A field method for determining the natural humidity of soils, by R. Kohler. The hydrologic triangle, by A. Geissler. Soils endangering buildings during frost periods, their recognition, and their effects in road constructions and high buildings, by K. Schober.*

Serpentin- und Chromerz-Geologie der Balkanhalbinsel und Eines Teiles von Kleinasien. GUSTAV HIESSLEITNER. Pp. 255; figs. 108; tbl. 1; pls. 12. Geol. Bundesanstalt Jahrb., Sonderband 1, Wien, 1951. *Serpentine and chrome ore geology of the Balkan Peninsula and of part of Asia Minor. Volume 1 describes the different chromite-bearing peridotite areas. The second part (still in press) will be a more theoretical treatment of chromite-bearing rocks.*

Der Wasserschatz im Gesteinskorper Württembergs. MANFRED FRANK. Pp. 252; figs. 31. Stuttgart, 1951. Price, 18.80 DM. *The water content of the rocks of Württemberg. General principles of water distribution, followed by specific descriptions of formations and their water-bearing properties.*

Titan. Pp. 481; figs. 41. Gmelins Handbuch der Anorganischen Chemie, System-Nummer 41, Weinheim/Bergstrasse, 1951. *A detailed description of all facts concerning the element titanium—its geologic occurrence including references to deposits throughout the world, its recovery as titanium oxide and titanium metal, its physical, electrochemical, and chemical properties, its alloys and its many chemical compounds. A storehouse of information.*

Dioptergoniometer für Gefugemessungen im Bereich magnetischer Erzvorkommen. HANS J. KOARK. Pp. 6; figs. 2. Stuttgart, 1951. *A sight goniometer for structure measurements in regions of magnetic ore occurrences.*

Zur Tektonisch-Petrographischen Analyse der Kalkbruche bei Burtrask in Vasterbotten. HANS J. KOARK. Pp. 38; figs. 12. Geol. foren. Stockholm Forh., Stockholm, 1951. *Petrofabric study of a limestone—leptite—amphibolite series.*

De Scheikundige Samenstelling der Aarde. J. WESTERVELD. Pp. 267; figs. 15; tbls. 22. Servire's Encyclopaedie, Servire, Den Haag, 1951. *The origin, evolution, and composition of the earth.*

Geology and Metallogenesis of Serifos Island. G. MARINOS. Pp. 32; figs. 26; tbls. 13. Subsurface Research Dept.—Ministry of Coordination, Athens, 1951. *Includes descriptions of contact metasomatic magnetite deposits and hydrothermal hematite replacement bodies. In Greek with English abstract.*

Hungarian Technical Abstracts. MAGYAR MUSZAKI LAPSZEMLE. Pp. 41. Hungarian Central Office for Technical Documentation, No. 5, Budapest, 1951. *Table of contents, and abstracts of leading articles, published in Hungarian periodicals during early part of 1951.*

The Geology of the Country around Gwelo. R. TYNDALE-BISCOE. Pp. 145; figs. 10; pls. 18. Geol. Survey Bull. 39, Salisbury, 1949. Price, 6s. 6d. *Area intruded by 3 granitic batholiths as well as basic and ultrabasic bodies. Descriptions of the Great Dike, and of gold, chromite, and other mineralization.*

Geology of the Sulphide Deposits at Menstrask and a Comparison with other Deposits in the Skellefte District. ERLAND GRIP. Pp. 52; figs. 19; tbl. 1; pls. 4. Sveriges geol. undersokning, Ser. C, No. 515, Stockholm, 1951. Price, 4 kr. *Sulfide ore lenses in conglomerates, below an impounding slate layer, consist of pyrite with varying amounts of pyrrhotite, sphalerite, chalcopyrite, and other sulfides. Part of differentiation attributed to squeezing of partially crystallized ore solution.*

Tungsten and Molybdenum in Sulphide Ores in Northern Sweden. ERLAND GRIP. Pp. 17; fig. 1; tbls. 5. Geol. foren. Stockholm Forh., Stockholm, 1951. *Scheelite is not rare in paragenesis of sulfide minerals and most commonly associated with pyrrhotite.*

SCIENTIFIC NOTES AND NEWS

The American Association of Petroleum Geologists announces the following slate of officers elected to take office for 1952–53. MORGAN J. DAVIS, President, JOHN G. BARTRAM, Vice President, ROBERT H. DOTT, Secretary-Treasurer, KENNETH K. LANDES, Editor.

JESS LARSON, Administrator of the Defense Materials Procurement Administration, announces the following appointments in addition to that of HOWARD I. YOUNG as Deputy Administrator. JAMES DOUGLAS, Assistant Deputy Administrator, TOM LYON, Director of Domestic Expansion Division, CHARLES E. STOTT, Director of Foreign Expansion Division, HAROLD MONTAG, Director of the Mining Requirements Division, JOHN G. FORD, Acting Director of the Contract Negotiations Division, and A. B. PARSONS, Acting Director of the Program Development Division.

The Arizona Geological Society will hold its 48th annual meeting April 11th and 12th at the University of Arizona in Tucson. The chief feature of the program will be a panel discussion on orogeny as follows. HUGO BENIOFF: Evidence from seismology on the nature of orogeny; W. H. EASTON: Evidence from stratigraphy on the distribution of orogenies in space and time; H. N. FISK: Sedimentation and orogeny, with particular reference to the Gulf Coast geosyncline; JAMES GILLULY: The connection between orogeny and epirogeny as deduced from the history of the Great Basin and the Colorado Plateau; and JEAN VERHOOGEN and FRANK TURNER: The relations of igneous and metamorphic rocks to problems of orogeny. The Seismological Society of America, the Mineralogical Society of America, and the Pacific Coast Branch of the Paleontological Society will also meet at this time. There will also be an informal panel discussion of the types of geological training currently desired and the opportunities that exist for advanced students. Four concurrent one-day pre-meeting trips and one two-day post-meeting trips are planned.

The program committee of the Cordilleran Section of the G.S.A. consists of EDWIN D. MCKEE, Chairman, and V. L. VANDERHOOF, CHARLES A. ANDERSON, and MASON L. HILL. There will be a panel discussion of mountain building; and a visit to the Ajo Mining Deposit conducted by ANDREW F. SHRIDE.

WILLIAM D. JOHNSTON, JR., Chief of the Foreign Geology Branch of the U. S. Geological Survey, has been elected a Foreign Member of the Brazilian Academy of Sciences. He returned to Washington, D. C., in December from a month's trip to South America where he visited Survey field parties at Belo Horizonte, Brazil, and Lima, Peru.

The Rice Institute announces the establishment of the HARRY CAROTHERS WIESS Chair of Geology. This Chair was made possible by a gift of $1,570,000 by Mrs. Olga Keith Wiess in memory of her husband, the late Harry Carothers Wiess, formerly Vice-Chairman of the Board of Trustees of the Rice Institute and member of the Corporation of the Massachusetts Institute of Technology. He was also a Charter Trustee and permanent member of the Board of Princeton University. It

is anticipated that the Chair will consist of a full professor of geology and two associates, and will devote its attention particularly to the field of marine geology. It is hoped that the selection of some, at least, of this faculty will be made in time to begin classes in the newly established division in September, 1952.

N. E. NELSON recently joined the U. S. Geological Survey to serve on the joint Bureau of Mines–Geological Survey field team for Defense Minerals Administration work and to handle copper applications in Washington, D. C. Mr. Nelson had been in charge of exploration for Wright-Hargreaves in Ontario, Canada, since 1944.

A. L. BROKAW resigned from the U. S. Geological Survey in October to accept a position as resident geologist for the St. Joseph Lead Co. at Balmat, New York.

The officers of SIGMA GAMMA EPSILON for 1952 are, C. B. CARPENTER of Golden, Colo.; W. R. HIGGS of Rolla, Mo.; P. D. PROCTOR and RALPH ESAREY of Indiana Univ.; E. V. O'ROURKE of Ohio State; J. N. PAYNE of Univ. of Arkansas; and BRONSON STRINGHAM of Univ. of Utah.

H. E. HAWKES of the U. S. Geological Survey left Washington, D. C., November 4, for a three-month assignment in Abakaliki, Nigeria, West Africa, where he will conduct geochemical prospecting investigations in a lead-zinc area.

A new $900,000 geology building has been completed at the University of New Mexico in Albuquerque. The L-shaped building, three stories high with full basement, is modified pueblo-type architecture in keeping with other buildings on the campus. Total floor space is 60,000 square feet, about half of which will be occupied by related Federal agencies.

JOHN H. MOSES who recently joined the geological staff of Reynolds Mining Company has been appointed chief geologist succeeding the late O. C. Schmedeman.

GEORGE F. SEAGER of San Francisco, who was stricken with polio in September, is reported as gradually improving.

KENNETH SEGERSTROM left Washington, D. C., for Mexico City where he will join the U. S. Geological Survey Point IV Mission there, under the direction of Carl Fries, Jr.

F. M. CHACE has resigned from the U. S. Geological Survey to join the M. A. Hanna Co. in Crosby, Minnesota.

The Chemical, Metallurgical and Mining Society of South Africa is arranging a symposium on diamond drilling to be held in Johannesburg April 21–23, 1952. Following the technical sessions, tours will be arranged to operations in the gold and diamond mines of South Africa and in the copper properties of Northern Rhodesia.

Professor GEORGE W. TYRRELL of the University of Glasgow, Scotland, delivered an address on "Geochemistry of Sediments" at a meeting of the Geological Society of Washington on November 28.

R. W. VAN BEMMELEN, formerly a member of the Indonesian Bureau of Mines and Geological Survey and leader of the Indonesian Volcanological Survey, was appointed last September as professor of Economic Geology at the Geological Institute of the University of Utrecht, Netherlands.

JOSE CARLOS RODRIGUES, Brazilian in-service trainee with the U. S. Geological Survey and Assistant Professor at the University of São Paulo, Brazil, completed

a six months' training period in the Engineering Geology Branch and left for Brazil on December 29.

At Columbia University, Professor J. T. SINGEWALD, JR., Professor of Economic Geology at Johns Hopkins University, gave a series of three lectures on "Some Problems of the Shallow Veins Historically Approached" on January 9, 10, and 11; and Professor ELWOOD S. MOORE, Professor of Economic Geology at the University of Toronto (retired), gave a series of lectures on the following subjects: "The Pre-Cambrian Sedimentary Iron Ores," "The Sudbury District," and "The Origin of the Porcupine Gold Deposits" on January 14, 15, and 16.

R. K. BAILEY, geochemist with the Geochemistry and Petrology Branch of the U. S. Geological Survey, died December 4, 1951, after being with the Survey for thirty-nine years. His work was chiefly on the chemistry and mineralogy of potash salts in drill cores and cuttings from New Mexico and Utah. He was the first to recognize sylvite and carnallite in United States samples.

The joint meetings of the Southeastern Section Geological Society of America and Southeastern Mineral Symposium, sponsored by The Geology Department of Virginia Polytechnic Institute, will be held at Roanoke, Virginia, May 1, 2, and 3. The highlights include: (1) Panel discussion on employment opportunities in geology, (2) Geology and industrial developments in the South since 1940 (state-by-state summaries given by recognized authorities), (3) Installation of officers of Southeastern Section of the Geological Society by DR. T. S. LOVERING, President of the Geological Society of America, (4) Address by DR. WALTER H. BUCHER on "Fossils in Metamorphic Rocks," (5) A dozen outstanding papers on timely geological investigations covering ground water, coal geology, atomic energy as a geological tool, oil and gas possibilities, structural geology, Blue Ridge geology, causes of pillar bursts in coal mines, geology of the Great Gossan Lead, and work of southern state geological surveys, (6) Field trip covering pertinent features of geology of the Roanoke area. Inquiries should be addressed to, Byron N. Cooper, Box 634, Blacksburg, Virginia.

W. T. SCHALLER, mineralogist with the Geochemistry and Petrology Branch of the U. S. Geological Survey, recently succeeded in synthesizing colemanite, the most abundant natural calcium borate. Before 1930 colemanite was the main source of borax. The synthesizing process indicates a possible explanation of the natural formation of colemanite deposits.

RICHARD M. FOOSE, head of the Department of Geology at Franklin and Marshall College, and retiring Chairman of the Mining Branch Council of the American Institute of Mining Engineers, has been named their delegate to the 19th International Geologic Congress in North Africa this summer.

DR. LEROY SCHARON, Associate Professor of Geology at Washington University, St. Louis, was elected Chairman of the Mining, Geology, and Geophysics Division of the A.I.M.E. at the Institute's Annual Meeting in New York, February 18–21 and becomes a Director *ex-officio* of the Institute during his year of service.